# SEWAGE AND INDUSTRIAL WASTES

(Formerly Sewage Works Journal)

JOURNAL of the FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

## *Special Features*

1951 Literature Review—Research Committee

Biology of Sand Filters—Calaway, et al.

Analytical Method for Detergents

Photosynthesis Measurement—Abbott

MAY, 1952—VOL. 24, No. 5

*Make Plans to Attend*—

# SILVER ANNIVERSARY MEETING

OF THE

# FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

IN CONJUNCTION WITH

NEW YORK SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

HOTEL STATLER
NEW YORK CITY

*October 6-9, 1952*

FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS
325 ILLINOIS BUILDING CHAMPAIGN, ILLINOIS

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Aeration Tanks, Fairfield, Connecticut Sewage Treatment Plant, with Chicago Swing Diffusers and Precision Diffuser Tubes. Air is supplied by three Chicago Standardaire Blowers. Two Blowers are direct connected to electric motors and have a capacity of 2000 cfm each at 6.5 psi. One Blower is direct connected to a gas engine and has a capacity of 2100 cfm at 6.5 psi. Design flow of the plant is 4 M.G.D. Bowe, Albertson & Associates, Engineers.

The City of Fairfield, Connecticut, is assured of continuous and economical operation of the aeration battery in their new Activated Sludge Sewage Treatment Plant. Bowe, Albertson & Associates, Engineers, specified a Chicago Air Diffusion System to provide complete equipment for sewage aeration. Everything necessary from air to water is specifically designed and engineered as a unit to treat sewage and industrial wastes. The Chicago Standardaire Blower, Swing Diffusers and Precision Diffuser Tubes provide efficient, quiet, continuous operation at low cost. Over 100 Chicago Air Diffusion Systems have been specified or installed in Sewage Treatment Plants.

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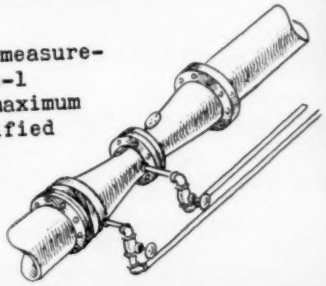
# FLOW CONTROL NOTES

Metering Raw Sewage Under Pressure

Problem: to measure raw sewage prior to treatment at point where it entered plant. Sewage, flowing through a 24" line under a head of about 20 feet of water, contained a high amount of suspended solids. Maximum flow--24 MGD; minimum--1.3 MGD.

Solution: 24" x 15.6" Simplex venturi tube with hand operated cleaning valves, clear-water flushing devices, and pressure chambers at main and throat sections. Also, low head, indicating, recording and totalizing meter, with a sediment tank in each connecting pressure line.

Result: accurate measurement over a 20-to-1 range, covering maximum and minimum specified flows. Cleaning valves and flushing devices keep tube and tanks clear.



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## MEMBER ASSOCIATION MEETINGS

| *Association* | *Place* | *Time* |
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| Michigan Sewage and Industrial Wastes Association | Park Place Hotel, Traverse City, Mich. | May 19–21, 1952 |
| Ohio Sewage and Industrial Wastes Treatment Conference | Commodore-Perry Hotel, Toledo, Ohio | May 21–23, 1952 |
| New England Sewage and Industrial Wastes Association | Hotel Elton, Waterbury, Conn. | May 22–23, 1952 |
| Alabama Water and Sewage Assoc. | Pitts Hotel, Auburn, Ala. | June 4–6, 1952 |
| Central States Sewage and Ind. Wastes Assn. | Loraine Hotel, Madison, Wisc. | June 25–27, 1952 |
| Pennsylvania Sewage and Ind. Wastes Association | Pennsylvania State College, State College, Pa. | Aug. 27–29, 1952 |
| Iowa Sewage Works Association | Grinnell College, Grinnell, Iowa | Sept. 9–11, 1952 |
| Rocky Mt. Sewage Works Assn. | Frontier Hotel, Cheyenne, Wyo. | Sept. 15, 1952 |
| Kentucky-Tennessee Industrial Wastes and Sewage Works Assn. | Andrew Johnson Hotel, Knoxville, Tenn. | Sept. 15–17, 1952 |
| South Dakota Water and Sewage Works Conference | Marvin-Hughitt Hotel, Huron, So. Dakota | Sept. 17–19, 1952 |
| German Sewage Technologists Assn. | Weisbaden, Germany | Sept. 17–20, 1952 |
| Mo. Water and Sewerage Conference | Governor Hotel, Jefferson City, Mo. | Sept. 21–23, 1952 |

### SILVER ANNIVERSARY MEETING

**Federation of Sewage and Industrial Wastes Associations**
**in conjunction with**
**New York Sewage and Industrial Wastes Association**
**Hotel Statler, New York City**
**October 6–9, 1952**

| | | |
|---|---|---|
| Pacific Northwest Sewage and Industrial Wastes Assn. | Multnomah Hotel, Portland, Ore. | Oct. 23–24, 1952 |
| The Canadian Institute on Sewage and Sanitation | Seigniory Club, Montebello, Que. | Nov. 3–5, 1952 |
| North Carolina Sewage and Industrial Wastes Assn. | Skyland Hotel, Hendersonville, N. C. | Nov. 10–12, 1952 |
| Florida Sewage and Industrial Wastes Association | San Carlos Hotel, Pensacola, Fla. | Nov. 16–19, 1952 |

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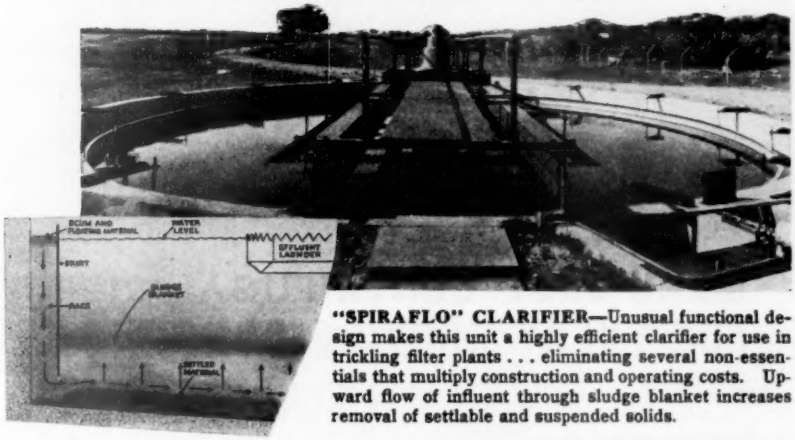


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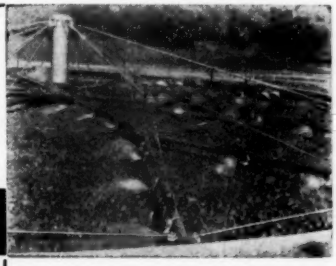

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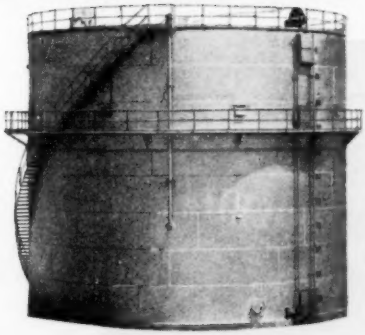

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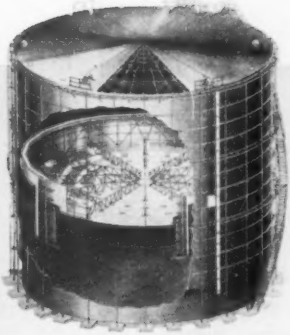

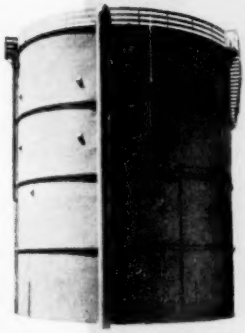

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*Established 1905*

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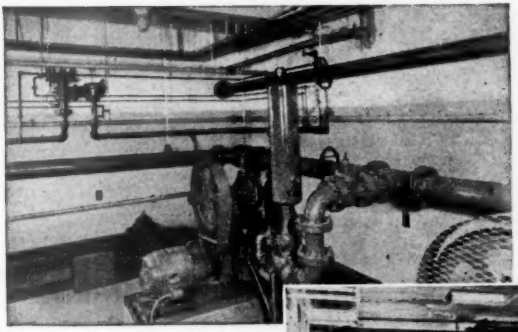

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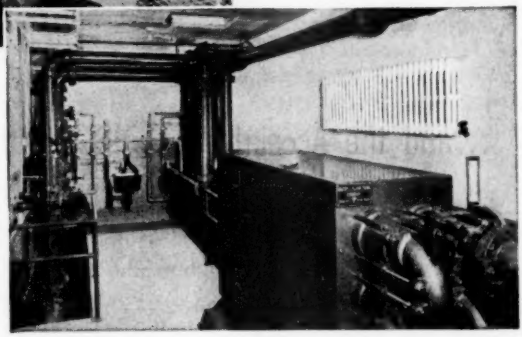

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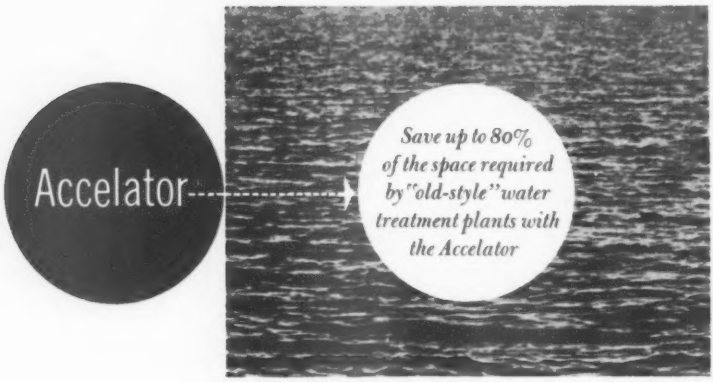


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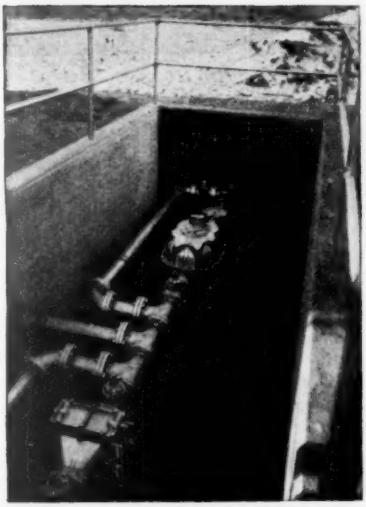

Valves take plenty of abuse in sewage treatment plant metering line service . . . But Nordstroms last and last.

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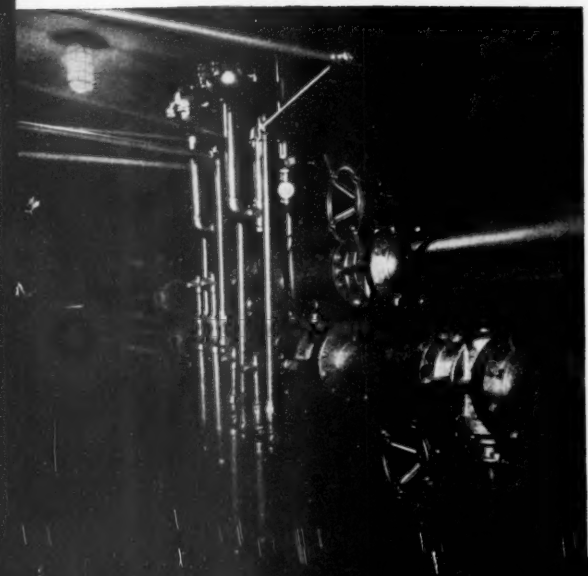

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## Way to improved sludge removal

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Gentle suction rather than conventional plowing or scraping—that's the Tow-Bro principle that means more efficient sludge removal. Rex engineers developed the Tow-Bro particularly for handling light, flocculent solids where *a minimum of agitation, high solids concentration* and *rapid sludge removal* are factors vital to good performance.

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**2. Greater Solids Concentration** . . . Tow-Bro principle assures much higher solids concentration than is obtainable with conventional scraper-type mechanisms.

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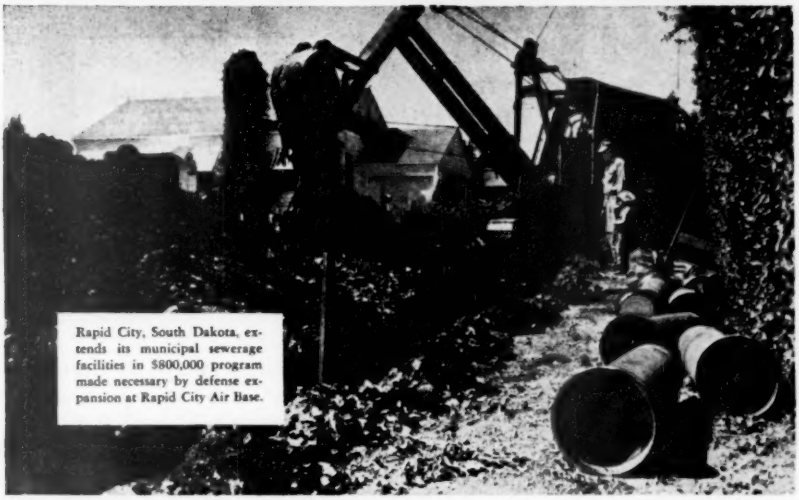

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C-852.3

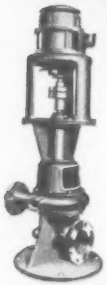
# NOTES

for the engineer's note book

—ON—

*Pumping with Economy*

**FOR SEWAGE MEN:**

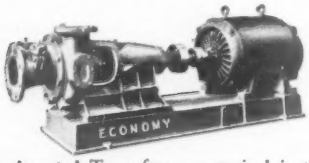


## UNSCREENED SEWAGE HANDLED By Wheeler-Economy Non-Clog Centrifugal Pumps

**For DRY PIT installations:**

Wheeler-Economy Horizontal or Vertical Centrifugal Sewage Pumps have clear waterways from 1½" to 10". They pump unscreened sewage, miscellaneous pulp or trash in liquid without difficulty. Where sewage is screened, Mixed Flow types are available for higher speed, more economical operation. Sizes to 36".

**"Sentry"** Type vertical pump with motor direct connected. For dry pit service, not subject to flooding, and to conserve floor space. CATALOG F249.




**Horizontal** Type for economical installation, accessibility and to simplify maintenance. CATALOG F447.

**Open Shaft** Type vertical pump with flexible shafting drive from motor. Motor located at distance above pump to avoid possible flooding of electrical equipment and to conserve pump room floor space. CATALOG F249.

**For WET PIT installations:**

**WHEELER-ECONOMY Sump Pumps**

Designed in single or duplex units to elevate drainage or sewage from wet pits, sumps, basements, boiler pits, scale and elevator pits, etc. Sizes from 1½" to 3" for drainage free from solids. Sizes 3" to 14", non-clog type for unscreened drainage containing solids. Sump cover and control arrangements can be supplied to meet any requirements. CATALOG E748 for General Service. CATALOG E345 for Non-Clog.

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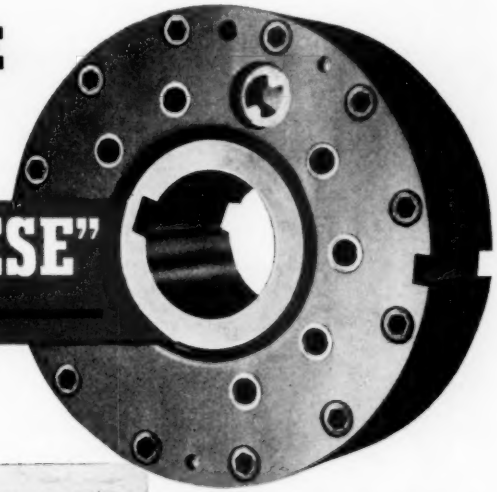
**In Sanitation Circles . . .**

## "HYDROLESE" HUB



All collectors in service at the Hyperion Sewage Treatment Works, City of Los Angeles, are "HYDROLESE" protected.

**Positive protection against overloads—elimination of troublesome shear pins . . certain when Jeffrey "HYDROLESE" Hubs are used on the countershafts with sprockets keyed to them.**

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- **Will not burn up.**
- **Will carry a definite torque load (Max. 30,000 lbs.).**

**Grit Washers**
**Grit Collectors**
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**Spiral Conveyors**

**Sludge Collectors**
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**Bucket Elevators**

**FLOCTROLS**
**Grinders**
**Chains**
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**This device has won wide favor in Sanitation circles—132 units used on the Los Angeles job. Send for complete information.**

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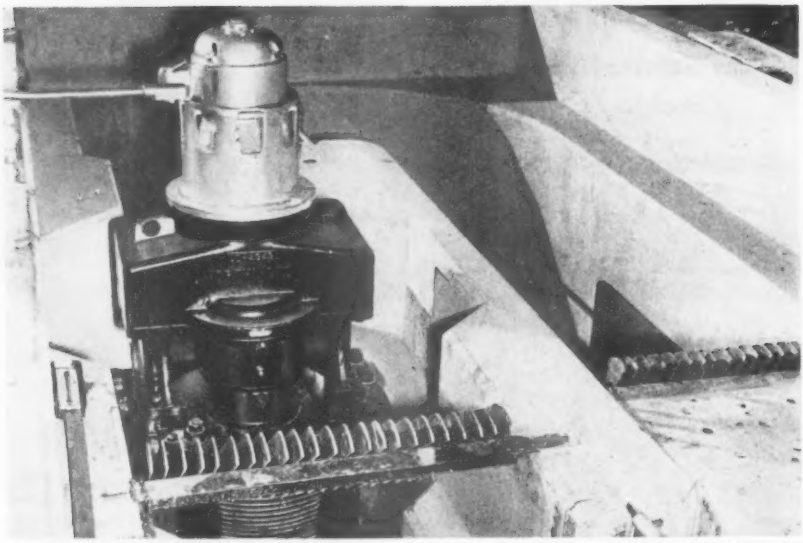
ESTABLISHED 1877
Complete Line of Material Handling, Processing and Mining Equipment



WORTHINGTON COMMINUTOR IS EASILY INSTALLED TO HANDLE LARGE VARIATIONS IN FLOW like this one at the Madison-Chatham (N. J.) Sewage Treatment Plant. Maximum wet-weather flows are occasionally as high as five times the average design dry-weather flow. An overflow screen is installed on top of the comminutor to screen flows in excess of the comminutor's capacity. Screenings are later raked down into the comminutor during period of normal flow. The overflow screen makes the comminutor independent of the by-pass on right which may later be used as a channel for a second comminutor. Plant Superintendent is Edward P. Molitor.

# Madison-Chatham, N. J., installation proves adaptability of Worthington COMMINUTOR

Typical example of the adaptability of the Worthington comminutor is the story of this installation at the Madison-Chatham Joint Meeting Sewage Treatment Plant in Chatham, N. J.

Engineers everywhere especially like the Worthington comminutor because:

- It can be readily installed in new or existing straight-flow rectangular channels.
- Cutter-racks are quickly removable for sharpening or replacement.
- It may be flooded without damage because it's protected by a mercury seal.

Worthington's public works specialists are ready to work with your community's engineer in solving screening problems—as well as other problems in sewage, water works, or municipal power generation. Write for Comminutor Bulletin W-2010-B3. Worthington Corporation, formerly Worthington Pump and Machinery Corporation, Public Works Division, Harrison, N. J.

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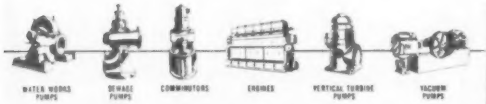
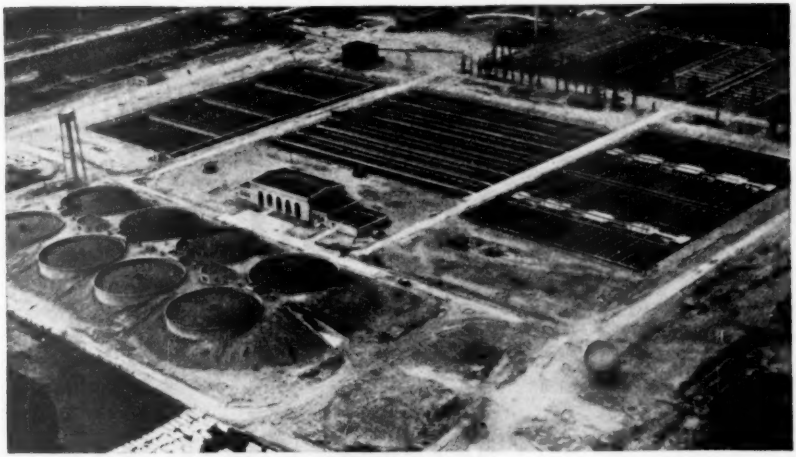
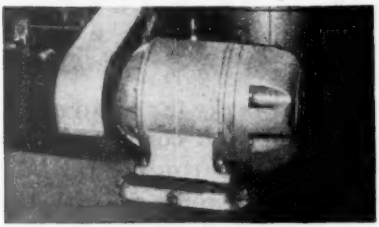



All Major Public Works Equipment Under One Responsibility

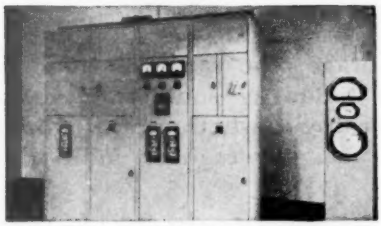
**WORTHINGTON**

Public Works Equipment





Motors



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Unit Substations

G-E application engineers select products like these to form the co-ordinated electrical system that exactly fits your plant requirements.

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# CLEAN WATERS

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1. Aids you in winning public support through the G-E packaged program "Modern Sewage Treatment" including the color sound movie *Clean Waters*.

2. Assists your engineers or consultants in the formation of electrical plans.

3. Manufactures a complete line of dependable electric equipment for sewage treatment plants.

To take advantage of this complete, three-way service, contact your G-E representative *early in the planning stage* when he can help you most. *General Electric Co., Schenectady 5, N. Y.*

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*to aid peak*
*defense production*

# Collect and Sell your Iron and Steel Scrap

**Mr. Q-Check says *dig* for scrap metal —*search* every nook and corner of your pipe yard—*scrape* the bottom of the barrel! For iron and steel scrap is critically needed to aid peak defense production in steel mills and iron foundries.**

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**Obsolete fittings; cut pipe (short pieces of distribution or service pipe); damaged hydrants, valve boxes, manhole covers, etc. It all adds up to a vital contribution to defense production.**

**Collect your scrap now. Phone your nearest scrap dealer. He wants what you have *but quick*, and pays good cash prices.**

**CAST IRON PIPE RESEARCH ASSOCIATION . . . CHICAGO**

# SEWAGE AND INDUSTRIAL WASTES

*Journal of the Federation of Sewage and Industrial Wastes Associations*

Volume 24 | MAY, 1952 | Number 5

## Contents

**1951 Literature Review**

A Critical Review of the Literature of 1951 on Sewage, Waste Treatment, and Water Pollution. By FSIWA Committee on Research

Introduction ..... 541
Analytical Methods ..... 543
Sewage ..... 550
Industrial Wastes ..... 579
Radioactivity ..... 602
Water Pollution ..... 614

**Sewage Works**

Heterotrophic Bacteria Encountered in Intermittent Sand Filtration of Sewage. By W. T. Calaway, W. R. Carroll, and S. K. Long ..... 642

Shallow Clarifier at Wheatridge, Colo. By Carroll H. Coberly ..... 654

Determination of Active Content of Anionic-Type Detergents by the Methylene-Blue Method ..... 658

**Industrial Wastes**

Rag, Rope, and Jute Wastes from Specialty Paper Mills. II. Load Distribution and Effect on Total Mill Effluent. By Willem Rudolfs and N. L. Nemerow ..... 661

**Stream Pollution**

Analysis of Polluted Waters Capable of Photosynthesis. By W. E. Abbott ..... 666

**The Operator's Corner**

Froth Formation and Synthetic Detergents. By W. N. Wells and C. H. Scherer ... 670

Tips and Quips ..... 679

**Editorial**

Suds and Syndets ..... 682

**Reviews and Abstracts** ..... 684

**Proceedings of Member Associations**

North Carolina Sewage and Industrial Wastes Association ..... 196a

North Dakota Water and Sewage Works Conference ..... 198a

**Equipment and Supply Lines** ..... 202a

W. H. Wisely, *Editor*, 325 Illinois Building, Champaign, Illinois
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**B.O.D. *reduced over 98%***
***. . . from 3000 ppm to 33 ppm!***

That's the job this industrial waste treatment plant is doing at the L. A. Dreyfus Company in Oaktree, New Jersey. Installed in a residential neighborhood, the plant plays an important part in this Company's comprehensive waste treatment control plan. The flowsheet includes equalization and pre-digestion in special 30′ dia. Dorr Digesters followed by the Biofiltration System using a Dorr Clarifier and a Dorrco Distributor.

There's no "cure-all" for industrial waste treatment. But there's a good chance that Dorr's diversified equipment and diversified experience can add up to the *right* kind of solution. The L. A. Dreyfus Company's installation is just one example.

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# 1951 Literature Review

## A CRITICAL REVIEW OF THE LITERATURE OF 1951 ON SEWAGE, WASTE TREATMENT, AND WATER POLLUTION

By W. Rudolfs, *Chairman*, D. E. Bloodgood, G. P. Edwards, M. B. Ettinger, H. A. Faber, W. H. Gehm, P. D. Haney, R. L. Harris, H. Heukelekian, R. D. Hoak, P. W. Kabler, M. Katz, C. E. Keefer, R. Manganelli, P. H. McGauhey, H. J. Miles, F. W. Mohlman, W. A. Moore, H. E. Orford, G. A. Rohlich, C. C. Ruchhoft, N. H. Sanborn, L. R. Setter, H. A. Trebler, and L. W. Van Kleeck

*Committee on Research, Section A, Federation of Sewage and Industrial Wastes Associations*

The review for 1950 * covered an all-time high number of references, but this year the literature available and examined materially exceeds any previous review. The mass of material has become so large that the effectiveness of the review in its old form loses considerable value, because of the difficulty in finding the references pertaining to various sections. This difficulty was overcome in a previous review of the literature dealing with toxic materials † where the references followed each specific section. Stimulated by the laudatory comments received, plus suggestions from some committee members, the present review has attempted to follow a procedure which seems more logical. The new method of presentation necessarily required redistribution of the member contributions in some cases, whereas in other cases the assembling of the review was simplified. It is hoped that the new procedure will make the review even more usable.

For several years attention has been called to the growth of literature pertaining to industrial wastes. In addition to more extensive coverage for all types of wastes, the references for radioactive materials have increased from none a few years ago to 94 this year.

The activated sludge process is considered by some as fickle, difficult to operate, and able to handle only comparatively moderate loadings. Some years ago Greeley,‡ on the basis of a survey, came to the conclusion that with average domestic sewage 25 to 30 lb. of applied B.O.D. per 1,000 cu. ft. of tank is a conventional load, although under some conditions much higher loads had been obtained. Since then, plant operation records have been published showing as much as 65- to 70-lb. B. O. D. loads. This year Pasveer (135) published results on increased aeration capacities where the loadings at a small plant treating domestic sewage were increased to 220 lb. per 1,000 cu. ft. of tank, or more than 3 times the higher loadings previously reported. It appears that design modifications or improvements may result in far smaller plants, hence less cost.

An interesting example of application of an old principle demonstrated to be feasible many years ago occurred this year with sludge concentration by

* This Journal, **23**, 5, 555 (May, 1951).
† This Journal, **22**, 9, 1157 (Sept., 1950).
‡ *Sewage Works Jour.*, **17**, 6, 1135 (Nov., 1945).

flotation ("Laboon process"). The information was available, but no one put it to practical use.

In the industrial waste field, considerable discussion has taken place regarding use of chlorine for phenol oxidation, whereas chlorination of metal plating cyanide wastes has reached the plant scale. The possible applications of chemical methods to a variey of industrial wastes for effective and efficient treatment has been by no means exhausted. In this respect, an important contribution by the Federation in the form of the "Chlorination Manual" should not be overlooked.

For the first time a rather extensive study dealing with vegetable contamination and decontamination was published during the year. The papers, as abstracted, reviewed, and commented upon in many domestic and foreign publications, have brought THIS JOURNAL to the widespread attention of scientists, investigators, students, and practitioners. The broader approach to the problems of sewage and waste treatment will doubtless stimulate intensive study during the next several years in many parts of the world.

By-products recovery possibilities from sewage and wastes received a substantial impetus by the results published on vitamins in sludge. Use of vitamin-rich sludges, other than mycelium from antibiotic production or wastes from fermentation industries, may be the beginning of a new by-product development.

Basically new treatment processes have not been disclosed, although possible applications of ultrasonic methods for suspended solids removal, sludge dewatering, disinfection, and stabilization of sewage have been indicated.

The most outstanding development in methods of analyses has been the membrane bacteria filter. The use of the filter for evaluation of water pollution and as an aid in detecting specific types of disease-causing organisms may be of great importance in affecting methods of treatment and requirements for treatment.

Publications dealing with stream pollution have greatly increased, indicating greater interest, broader enforcement, more specific regulations, and extended information. Reports concerning sewage of 8 major drainage basins, showing the pollution discharged, damages wrought, benefits which may accrue as a result of pollution prevention, and pollution prevention in effect and required, disclose that some 10,000 municipal and industrial waste sources need rectification at an estimated cost of from $9,000,000,000 to $12,000,000,000 during the next decade. In respect to future developments for abatement of pollution the National Technical Task Committee on Industrial Waste can be very important and effective, once it gets firmly underway.

Further emphasis has been placed on the trend to consider stream quality rather than effluent quality standards and zoning for best usage of streams by the new New York standards and classifications. The Ohio Valley bacterial standards should be mentioned in this connection.

Another important step forward are the tentative standards for sewage works proposed by the Joint River Board of the Upper Mississippi and the Great Lakes Board of Public Health Engineers. The tentative standards appear to be the beginning of uniform design standards for the entire country—standards which seem realistic, easily interpreted, and modern in concept.

Specific attention is also called to the decision of the U. S. Supreme Court regarding the constitutionality of the Ohio compact, which undoubtedly will have repercussions and be a guide for interstate cooperation.

The need for adequate and equitable service charges for sewage and industrial wastes is still evident. The comprehensive report by the Joint Committee of a number of organizations is

a distinct contribution, an important guide, but, as indicated by the report, no solution for local conditions. Undoubtedly, detailed studies will be forthcoming to solve the increasing pressure of municipal financial problems.

The Research Committee has never singled out any section of its annual report, but attention is called to the review dealing with biology, which in effect is an outstanding, extensive review, particularly of obscure foreign literature, on the effect of wastes on fish life.

## ANALYTICAL METHODS

### B.O.D. and Oxygen Consumed

Gellman and Heukelekian (10) discuss the limitations of the "standard" dilution method for the determination of B.O.D. as compared to manometric methods. Factors concerned with the manometric determination, such as $CO_2$ absorption, nitrification, agitation, and sample volume, were studied. They concluded (a) that the highest oxidation rates obtainable with the Sierp and Warburg apparatuses are 520 and 360 p.p.m. per hour, respectively, (b) that the reproducibility is equal to that obtained by the standard dilution method, and (c) that oxygen demand measurements may be 20 per cent higher for organic compounds and 14 per cent higher for domestic sewage by the direct method. Ludwig *et al.* (18) also studied extensively the direct method for determining B.O.D. by means of the Warburg apparatus. They present a simplified procedure for use in making the necessary calculations. These authors believe that the method offers advantages over the standard dilution method, but that the technique must be simplified before it can be used for routine determinations.

Chakravarti and Som (5) compared the 5-day B.O.D. values of a vegetable waste, an activated sludge plant effluent, and several septic tank effluents with those obtained by chemical oxidation. The chemical method used was oxidation with dichromate in a $H_2SO_4$-$H_3PO_4$ mixture at 140° to 145° C. The excess dichromate was titrated iodometrically. The oxygen consumed values multiplied by 0.68 were slightly higher than the 5-day B.O.D. in about one-half the cases and considerably higher in the remainder due to the presence of cellulosic material.

Moore and Ruchhoft (28) point out that B.O.D. and oxygen consumed are two distinct parameters and are not interchangeable. In domestic sewage from which the settleable solids have been removed and by using certain conditions for determining the oxygen consumed, a close correlation was obtained between these two parameters. In streams receiving domestic sewage the O.C./B.O.D. ratio increases with increasing biological stabilization. The authors also stress the fact that where a given industrial waste is fairly constant in composition and contains no toxic compounds, a satisfactory correlation can be obtained between the oxygen consumed and the biochemical oxygen demand.

Continued interest was shown in the determination of oxygen consumed of organic materials. Pirogova (35) modified the permanganate method of Skopintzev* by pretreating the sample with alkali and boiling for 10 min., followed by neutralization before oxidizing with permanganate. Knox and Pask (16) used 0.1 *N* dichromate in a $H_2SO_4$ solution for the determination of diethyl ether and ethyl alcohol in blood samples. The sample is adsorbed on filter paper suspended above the oxidizing solution. The temperature of digestion is 3 to 4 hr. at 37° C. An accuracy of $\pm 2$ per cent is claimed. It is obvious that the method would be applicable only to highly volatile compounds.

Medalia (24), in determining the presence of trace organic material in

* *Jour. Appl. Chem.* (U.S.S.R.), **7**, 1294 (1934).

water, relied on the reaction between ferrous iron and hydrogen peroxide. This reaction initiates a chain reaction in which the organic compounds react with the molecular oxygen present. The results obtained are higher in most cases than with permanganate, but lower than those obtained with dichromate. Shaw (41) determined the oxygen consumed values of coke plant wastes by using chromic acid as the oxidizing reagent. The reaction is carried out in the presence of $H_2SO_4$ and $H_3PO_4$. The mixture is heated for 5 min. in a steam bath and the excess chromic acid reduced with an excess of ferrous iron. The excess of the latter is then determined by titration with dichromate. Chlorides are not attacked.

Riehl (37) reviewed the various methods for determining oxygen consumed, with chief emphasis on the dichromate reflux method of Moore. Pepinsky *et al.* (34) describe a rapid dichromate procedure for the oxidation of organic wastes. The reaction is carried out in the presence of phosphoric and sulfuric acids and the heating time is such that a temperature of 165° is reached in 6 min. The excess dichromate is determined iodometrically. Chloride is oxidized quantitatively and silver sulfate could be used as a catalyst providing the starch was used as an outside indicator. If the heating time is extended, breakdown of the dichromate results and high oxygen consumed values are obtained.

Moore *et al.* (29) made a statistical comparison of the oxygen consumed results obtained by three dichromate modifications, the "standard" permanganate method, and an iodic acid method. Pure organic compounds, as well as typical industrial wastes, were used in the study. With some materials as many as 100 determinations were made. The use of silver sulfate as a catalyst increased the percentage oxidation with most samples. This is especially true with straight-chain acids and alcohols. The results obtained in this study indicate that the Moore dichromate method † would give the most reproducible results with a wide variety of samples. With the iodic acid method and on those methods in which the excess dichromate is determined iodometrically, the use of silver sulfate as a catalyst is precluded.

### Dissolved Oxygen

Verbestel *et al.* (47) made a critical study of the various methods for the determination of dissolved oxygen in concentrations around 0.01 p.p.m. It is pointed out that limitations in the iodometric titration make the Winkler method unsuitable for determining trace amounts of dissolved oxygen. Of the colorimetric methods that have been proposed, it was found that the o-tolidine method was the most suitable.

Splittgerber *et al.* (44) and Meyer and Brack (26) also investigated the determination of dissolved oxygen by means of o-tolidine. The latter authors state that from 0.02 to 15 mg. per liter of dissolved oxygen can be determined in clean waters. They eliminate iron interference by the addition of $Na_4P_2O_7$. Both papers give detailed directions for the determination of dissolved oxygen by this method.

Wickert (49) found that the toluidine method was satisfactory if the iron content was not over 0.02 mg. per liter. If iron in excess of this amount is present, low dissolved oxygen values are obtained. This error can be avoided if thiocyanate is used in conjunction with the toluidine method. The oxygen equivalent of the ferrous to ferric iron is added to the dissolved oxygen as determined by the regular toluidine method.

Rand and Huekelekian (36) compared the dissolved oxygen results by the Winkler and polarographic methods on industrial wastes. The waste was first boiled to remove any dissolved oxygen and then known increments were added. It is claimed that the polarographic method permitted reasonably accurate determination of

† *Anal. Chem.*, **21**, 953 (1949).

the dissolved oxygen. A detailed procedure is given for the determination. Stone and Eichelberger (45) describe an apparatus for the preparation of water of a known oxygen content, as well as that used in the titration of dissolved oxygen in an atmosphere of $CO_2$. The latter consists of a 1.0-ml. titration burette, graduated to 0.01 ml. and provided with a reagent reservoir and a 3-way pressure stopcock. The method consists in adding the water sample to an excess of chromous chloride, the excess $Cr^{++}$ then being oxidized with an oxygen-free solution of $KIO_3$. Potassium iodide is added and the liberated $I_2$ is titrated with chromous chloride in the presence of starch indicator. The presence of 10 p.p.m. of nitrite results in an increase of 0.7 per cent in the dissolved oxygen values.

Marsh (23) developed a portable polarograph using a rotating platinum electrode for determining dissolved oxygen in oil-field brines. An accuracy of $\pm 5$ per cent is claimed for the instrument. It is possible to detect differences of 0.02 mg. per liter of dissolved oxygen, even though the absolute error may be greater than this. Moggio and Burland (27) propose a method for the standardization of standard thiosulfate solution by using saturated solutions of dissolved oxygen. The method is fast and simple and an accuracy is claimed equal to that obtained with primary standards. Corrections must be made for barometric pressure and temperature.

## Nitrogen

The determination of nitrogen in its various forms continued to interest many research workers during the year. Thompson and Morrison (46) made a detailed study of the determination of organic nitrogen by means of Nessler's reagent. The variables studied by these workers included correct Nessler reagent, presence of organic material, sulfate concentration, alkalinity of Nesslerized sample, temperature during Nesslerization, effect of time of reading after Nesslerization, and the presence of metals which will react with iodine. They found that all of these factors affect the final color formed and the amount of turbidity present in the Nesslerized sample. Wiebke (50) determined small amounts of ammonia in the presence of hydrazine by precipitating the latter with $CuSO_4$ in a sulfuric acid solution. The copper complex is allowed to settle at about 5° C. and filtered off. The ammonia was distilled into standard acid with methyl purple used as an indicator.

Hayazu (11) used dry air instead of steam in expelling the ammonia in his micro-Kjeldahl determination. White and Long (48) carried out the micro-Kjeldahl digestion in sealed tubes in the presence of $H_2SO_4$ and mercuric oxide. After reaching temperature the digestion is continued for 15 min. The method was found to be quite effective in the determination of various types of organic nitrogen which might be encountered in industrial wastes. Marquex and Alliota (22) in the Kjeldahl nitrogen determination add $K_2S_2O_8$ and $H_2O_2$ in addition to the sulfuric acid. After carbonization of the organic matter has taken place, the mixture is boiled and a second portion of both the $K_2S_2O_8$ and $H_2O_2$ is added. Boiling is continued for 20 to 30 min., after which the mixture is made alkaline and the $NH_3$ is distilled off. Jenkins (13) studied the effect of urea hydrolysis on the determination of $NH_3$ in sewage. He found that urea was completely hydrolyzed to $NH_3$ by incubation for 2 hr. at 33° to 35° C. in the presence of five urease tablets per liter, or by standing at room temperature for 24 hr. without the addition of urease. Secondary and final tank effluents, on the other hand, showed no increase in $NH_3$ content either with or without the addition of urease, due no doubt to the prior hydrolysis. He concludes that fresh sewage should be allowed to stand 24 hr. before the $NH_3$ is determined,

unless it is desirable to know the urea content. Jenkins (14) also determined organic nitrogen in sewage, effluents, and river waters by boiling the sample with caustic and Devarda alloy prior to digestion with sulfuric acid and distillation. Buljan (3) used a method for the determination of $NH_3$ in sea water based on its action on a hypobromite in an alkaline solution. In an acid solution the $NH_3$ will not react. Therefore, hypobromite is added in equal quantities to two samples of sea water, one of which is acidified. The excess hypobromite is estimated volumetrically by the addition of a Bordeaux B dye solution. Jenkins (15) determined nitrite plus nitrate by heating the residue from the $NH_3$ determination with Devarda alloy and distilling into N/140 $H_2SO_4$.

## Phenols

With increased interest in stream pollution by industry, a wide variety of problems has arisen in the analysis of industrial wastes. To evaluate all of the analytical procedures applicable to such wastes that have been published in the past year would be a major problem. However, certain methods have been published that are applicable to a wide variety of industrial wastes.

The phenolic group of compounds, due to their taste- and odor-producing characteristics in water supplies, have received considerable attention from the analytical standpoint. Ettinger and Kroner (7) discuss in detail the necessary steps involved in their determination in industrial wastes. These steps may involve one or more distillations, alkaline evaporation, solvent extraction, and precipitation of interfering materials. The final evaluation may be made colorimetrically by either the Gibbs or the 4-aminoantipyrine methods. Ettinger *et al.* (8) evaluated the various factors involved in the determination of phenol by the 4-aminoantipyrine method. The factors studied included effect of pH, temperature, order of addition of reagents, reagent concentration, etc. It was found that greater sensitivity could be obtained by extracting the color with chloroform. The method is sensitive to about 2 p.p.b. with this procedure when applied to surface waters. Dannis (6) also investigated the 4-aminoantipyrine method for the determination of phenols in coke plant wastes. He studied some of the factors involved and concluded that the method could frequently be used without preliminary distillation. The time involved in this case is about 10 min. Shaw (42) also studied the determination of phenol in coke plant wastes and for phenol concentrations above 30 p.p.m. used a bromination procedure. For low concentrations of phenols he used the 4-aminoantipyrine method, for which he claims a sensitivity of about 20 p.p.b. In this case, however, the color formed is read in the aqueous phase, no extraction procedure being used. Shaw stresses the fact that the factors controlling the reaction must be rigidly adhered to. Another approach to the determination of phenolic compounds was made by Simard *et al.* (43) by means of infra-red spectroscopy. These workers used bromination as the first step, with subsequent extraction of the bromphenols with $CCl_4$. The optical density of the extract is measured at 2.84$\mu$. Less than 10 p.p.b. of phenol can be determined.

## Oils

Simard *et al.* (43) determined oil on the same $CCl_4$ extract used for the determination of phenolic compounds. In this case the optical density was measured at about 3.4$\mu$. A mixture of cetane, iso-octane, and benzene was used as a reference standard. It is claimed the method is sensitive to 0.1 p.p.m. of oil in a water sample. Musante (30), in the determination of oil in refinery waste waters, extracted serially a 3-l. sample (acidified with HCl) with nitration grade benzene,

The solvent is removed by careful distillation and the oil residue weighed.

### Organic Compounds

Braus *et al.* (2) outline a procedure for the isolation of organic compounds in water, which no doubt could be applied also to the study of various industrial wastes. The method consists essentially of passing a large volume of the water through an activated carbon filter, which adsorbs the organic compounds present in the water. The carbon is extracted with ether or chloroform. The residue from this extract is broken down by micro-organic methods into various groups, such as phenolic, neutral, acidic, amphoteric, and basic. These groups can be further separated by micro-techniques into the organic compounds present.

### Color

In many cases it is advantageous to know the color intensity of an industrial waste that is to be discharged to a receiving stream. Rudolfs and Hanlon (39) have proposed a spectrophotometric method for determining the absorption characteristics of waste samples. These characteristics are related to the tristimulus values and a standard illuminant source. Results are expressed in dominant wave length (millimicrons), luminance (per cent), and purity (per cent). The transmission characteristics are determined at pH 7.6 and also at the pH of the waste sample. The same authors (40) also propose a more simplified method using tristimulus light filters combined with a specific light source and photoelectric cell for the determination of the color of industrial wastes. The results obtained by this method are approximately the same as those obtained by the spectrophotometric method.

### Cyanides

One of the most toxic constituents of industrial wastes, particularly by-product coke and metal finishing waste, is the cyanide radical. Many methods have been proposed for its determination and research is still being conducted. Kruse and Mellon (17) review the determination of cyanide by the pyridine-pyrazolone method and claim greater sensitivity and color stability for it than by the pyridine-benzidine method. No experimental data are given. Nusbaum and Skupeko (31) studied the determination of cyanide in sewage and polluted waters by the pyridine-benzidine method. They formed the cyanogen-halide by the addition of bromine to the sample acidified with $H_3PO_4$. The excess Br was destroyed with sodium arsenite. Butyl alcohol is used as the extractant for the cyanogen-bromide and the color is developed in the alcohol layer on the addition of the pyridine-benzidine reagent. Free cyanide can be determined by this method in the range of 0.02 to 0.50 p.p.m. with little interference. Thiocyanates can also be determined by the proposed method. Will (51) made a comparison of various methods for the determination of cyanide. The methods studied (no experimental data are given) included the Liebig, phenolphthalin, pyridine-benzidine, and pyrazolone procedures.

### Metallic Ions

The determination of metallic ions in industrial wastes has assumed increased importance, due to their toxic effect upon the biological equilibrium of the receiving stream. Butts and Mellon (4) studied the polarographic determination of such ions as Cu, Fe, Cr, Cd, Ni, and Zn in industrial wastes. Horvai (12) determined copper colorimetrically with the sodium salt of tetrabromophenolphthalein. The sensitivity of the method is not mentioned and it is necessary to remove both iron and chromium prior to the analysis. Fassett *et al.* (9) were able to determine from 0.06 to 15 $\mu$g. of Cr with an accuracy of 5 per cent by the diphenylcarbazide reaction by varying the

absorption cell length and the final volume.

### Chlorine

Chlorine is finding increased usefulness in the fields of sewage and industrial waste treatment and is no longer confined to the field of water treatment practice. Nusbaum and Meyerson (32) made a study of five methods for the determination of chlorine in checking the chlorine demand of sewage samples. They found excellent agreement between the p-aminodimethylaniline and acid starch-iodide methods. The neutral O.T. method also checked with these, but was harder to read, due to fading. The acid O.T. and neutral starch-iodide method showed no correlation. The authors also used an amperometric method. Lur'e and Nikolaeva (19) also studied various methods for the determination of free chlorine and chloramine in water. They recommend the methyl orange method for determining the chlorine demand of water. They state that in the arsenite-tolidine and p-aminodimethylaniline methods part of the monochloramine is calculated as free chlorine. Marks *et al.* (21), by the proper control of the iodide ion concentration and pH, were able to quantitatively separate hypochlorous acid, monochloramines, and dichloramines by amperometric titration. The hypochlorous acid is titrated at neutral pH with phenylarsineoxide, a small quantity of KI is added, and the monochloramine also is titrated at neutral pH. The pH is then lowered to 4, more KI is added, and the dichloramine is titrated. Williams (52) also determined free chlorine, monochloramines, and dichloramines by amperometric titration. He also compared the results obtained amperometrically with those obtained with the Palin colorimetric method. Nusbaum and Skupeko (33) used the well-known cyanogen-halide plus pyridine-benzidine reaction for the determination of free and combined chlorine. The free chlorine is destroyed by arsenite and the combined chlorine is determined by the same reaction. From 0.055 to 1.4 p.p.m. of available chlorine can be determined by the method. The authors claim the method is particularly suitable for use on sewage chlorination. Aitken and Mercer (1) describe a photometric method for the determination of free and combined chlorine by buffered o-tolidine at a pH of 7.0.

### Miscellaneous

Mestayer (25) used a volumetric method for the determination of sulfate in water samples. The sulfate is precipitated with an excess of 0.01 *N* $BaCl_2$, the mixture is evaporated to dryness, and then taken up in 50 per cent alcohol. The excess $BaCl_2$ is determined by titration with standard $(NH_4)_2SO_4$, using as indicator a mixture of Victoria blue, barium rhodizonate, and ignited talc.

Mannelli (20) and his co-workers have studied the use of adsorption indicators in the argentometric determination of halides and $SCN^-$. The ones which seem to be particularly useful are Bordeaux red and Orange II. With these, both $I^-$ and $Cl^-$ can be determined in the same solution.

Rose (38) describes a photo-extinction apparatus for the determination of turbidity in water samples. It is claimed the apparatus will give absolute results and that no calibration is required.

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## SEWAGE

### General

*Disease*

A series of papers was published by Rudolfs, Falk, and Ragotzkie (149) (150) (151) (152) (153) (154) on the contamination of vegetables grown on polluted soil. On the basis of the studies the general conclusion was drawn that there was no evidence that pollutional bacteria, amoeba, or helminth eggs penetrate healthy unbroken surfaces of vegetables, causing internal contamination. Vegetables to be eaten raw can be grown without health hazard in soils that have been subject to sewage irrigation, night soil application, or irrigation with polluted water in years prior to the season in which the vegetables are grown. Vegetables grown under conditions of surface sewage irrigation showed no higher coliform concentration that those grown on normally farmed soil. If sewage sludges or night soil are applied on

the surface of the soil or sewage effluents are applied by overhead irrigation during the growth of vegetables, such application should be stopped at least one month before harvest. Strains of *Salmonella* and *Shigella* do not survive on vegetable surfaces for more than one week, hence conclusions based on coliform contamination offer a considerable margin of safety. Bacteria applied to vegetable surfaces are tenaciously held and protected from the external environment, which permits their survival and explains the difficulty of their removal by artificial means. The resistance of cysts of *Endamoeba histolytica* to external environment depends almost entirely on the amount of moisture, because they die immediately upon desiccation. A lapse of at least one to two weeks after the last application of the contaminating material is required before harvesting to reduce the health hazard of amoebic dysentery. Although eggs of *Ascaris suum* were recovered in reduced numbers from vegetables one month after application, they had all degenerated. A lapse of one month after the last application of fecal matter prior to harvesting will reduce the hazard of transmission of *Ascaris* greatly. Storage or washing of vegetables in plain water or with water containing various detergents is ineffective as a means of decontamination for bacteria or for helminth eggs. Rinsing with water containing a germicidal concentration of chlorine is effective for decontamination against bacteria, but not for helminth eggs. The only reliably effective method for decontamination of bacterial, amoebic, and helminthic organisms is pasteurization at 60° C. for 5 min.

*Salmonella* organisms were recovered from a significant proportion of samples of irrigation water contaminated with effluent from primary tanks, but were not recovered from samples of vegetables irrigated with this water by Dunlop, Twedt, and Wang (40). Cysts of *E. histolytica* added to damp loamy soil remained viable for at least 8 days, whereas in clean aerated water they were culturable for 4 days or less according to Beaver and Deschamps (22).

A comparison of the survival of coliform organisms and enterococci in soil made by Mallmann and Litsky (113) showed that, whereas coliform organisms persist for long periods, the enterococci die out rapidly and virulent typhoid bacteria die out even more rapidly than the enterococci. The longevity of all these organisms was prolonged with an increase in the organic content of the soil. The authors concluded that enterococci appear to be good indicators of public health hazards from sewage in soil and vegetables.

A modification of Winter and Sandholzer media and technique for enterococci detection was suggested by Wang and Dunlop (192).

Scobey (162) calls for a reappraisal of the poliomyelitis problem on the basis of the failure of the virus theory to explain the disease adequately after an intensive period of research. The infectious and epidemic character of the disease has been over-emphasized, according to the author, at the expense of the more promising toxicological approach.

*Microbiology and Biochemistry*

A review of microbiological aspects of lignin degradation is presented by Gottlieb and Pelczar (56). No evidence of a specific or identified bacteria has been found in the literature associated with the natural degradation of lignin. Similarly, no enzyme preparation has been reported capable of bringing about the degradation of lignin. Hajny, Gardner and Ritter (63) reported the isolation of a thermophilic organism capable of fermenting not only sugars, hemicelluloses, and cellulose, but also a part of the cellulose in untreated wood. The main products of fermentation were acetic, butyric, and lactic acids in yields approximating 50 per cent of the carbohydrate consumed.

The yield of acids from untreated sawdust was 15.9 per cent of the weight of the dry wood. A prior mild acid hydrolysis of the sawdust increased the yield to 26.4 per cent.

Sisal, manila, hemp, flax, jute, artificial silk, nylon, and perlon were submitted to aerobic and anaerobic bacterial action by Von Wolzogen (189). The natural fibers were strongly attacked after 2 to 3 years and the artificial fibers in 3 months to 2½ years. The latter were more susceptible to aerobic decomposition than to anaerobic deterioration.

According to Silliker and Rittenburg (163) the ability to oxidize fatty acids is not an uncommon property of aerobic bacteria. *Serratia marcescens* was able to oxidize from 2-carbon to 14-carbon fatty acids. If the inoculum was derived from sugar medium the subsequent oxidation of the fatty acids manifested a lag period, although no such lag period was obtained when the inoculum was derived from a medium containing fatty acid. This is suggestive of adaptive enzymes. This conclusion was further elaborated upon in a subsequent paper by the same authors (164).

Biochemistry of nitrification in soil is reviewed by Quastel and Scholefield (142). A special technique of soil perfusion method used by the authors and the results obtained by this method are discussed. It was concluded that nitrification is a function of the degree of adsorption of the ammonium ions in the soils' base exchange complexes. This is interpreted to mean that nitrifying bacteria grow adsorbed on the surfaces of the soil crumbs at sites where ammonium ions are held in base exchange combination. When all the relevant sites at the surface have been occupied, further growth of the organisms does not occur except to replace cells which have died. Only a very few living nitrifying cells enter into the soil solution. This follows from the concept of bacteria saturated soil; namely, a soil where the area of proliferation is limited and cannot be extended owing to full occupancy of available sites. A soil saturated with nitrifying bacteria brings about a relatively rapid nitrification, but until the soil becomes saturated with nitrifying bacteria there is a lag period. The soil saturated with nitrifying bacteria acts like an enzyme system with no proliferation of the organisms except to replace the dead cells. If instead of ammonium ions, organic nitrogen compounds are fed, a soil saturated with nitrifying bacteria will manifest a lag period, indicating that organisms must first develop that can convert these compounds to free ammonia, which is subsequently nitrified.

Temple and Colmer (177) obtained from acid mine water an iron-oxidizing bacterium that lives autotrophically upon inorganic media containing ferrous iron under conditions such that atmospheric oxidation is excluded. This bacterium also grows autotrophically on thiosulfate and has, accordingly, been named *Thiobacillus ferrooxidans.*

With the use of the direct methods of oxygen utilization, the influence of factors such as pH value, nutritional deficiency and requirement, substrate concentration, and origin, volume, and character of seed on the biochemical oxidation of a number of wastes was studied by Heukelekian and Gellman (74).

## Sedimentation

The article by Poepel (139) on settling tank design which was abstracted last year by Keefer (88) has been discussed by Gifft and McKee (53) and Coberly (31), and rebutted by Poepel and Keefer (138). Coberly gives instances of satisfactory operation of sedimentation tanks designed on the basis of a formula similar to one proposed by Poepel.

The Cambridge, Mass., waterworks (39) has added two shelves to each of its 18-ft. deep settling tanks, thereby dividing the water flowing through

into three streams each about 5 ft. deep.

Schmitz-Lenders, Struder, and Peil (160) describe excellent results obtained over a 13-yr. period with large single-blade sludge removal mechanisms in settling tanks. The mechanism consists of a single parabolic-shaped scraper so constructed that the thrust of the scraper on the sludge is radial and toward the center, thus reducing the circumferential movement of the sludge. The scraper can be constructed in overlapping sections.

Thatcher and Lucas (179) describe developments simplifying the operation of rectangular sedimentation tanks and enabling existing tanks of good design to be modernized by installation of mechanical desludging facilities. It is stated that the operating costs of rectangular tanks using the improved system are significantly less than those of circular tanks.

Two reviews of current design practice have appeared. Gilbert (54) reviews current practice in this country and Grubb and Hancock (61) review English practice on upward-flow tanks.

Thoman (180) presents a statistical summary of grit chamber usage giving the number of sewage plants having grit chambers, with special reference to type of sewer system and selected operating data from a group of 30 plants.

Parshall (133) describes hydraulic model studies of a sand trap employing both the riffle-deflector and vortex tube principles, which may have some possible application in grit chamber design.

## Chemical and Mechanical Methods

### *Chemical*

Murray, Fischer, and Sabean (127) studied the effects of time and temperature of burning on quicklime properties. They report that porosity, surface area, and reactivity with water are closely related and that porosity is determined primarily by rate of heating during calcination.

Wooster, Ohio (36) uses chemical precipitation as an aid to plain sedimentation during periods of the year when the receiving stream cannot assimilate the plant effluent. With 17 p.p.m. ferric chloride and 170 p.p.m. calcium oxide the reduction in suspended solids increased 27.8 per cent and in B.O.D. increased 55.8 per cent.

Lumb (110) reviewed the history and present status of chemical precipitation in Great Britain. It is estimated that in 1937 about 10 per cent of 3,000 sewage treatment plants used chemicals for precipitation. The most commonly used chemicals are alum and lime.

### *Mechanical*

Two interesting articles on the application of ultrasonic vibrations in sewage treatment appeared during the past year. Coleman and Gotaas (33) review the basic principles of ultrasonics and its applications. They state that "coagulation has been accelerated, wet solids have been dewatered, microscopic organisms have been killed, immiscible liquids have been mixed, liquids have been degassed, and oxidation has been accelerated." Possible fields of application in sewage treatment appear to be in suspended solids removal, sludge dewatering, and sewage disinfection and stabilization, but at the present time these methods do not appear practical on the large scale required.

Lyon (112) reports experiments on the improved rates of sedimentation of activated return sludge and activated mixed liquor following ultrasonic vibrations. The former settled twice as fast after 10 min. of vibration and three times as fast after 15 min. of vibration as the unvibrated sludge. In the case of the mixed liquor, following 10 min. of vibration, the sample settled as much in 3 min. as the unvibrated sample settled in 15 min.

Two articles on sand filtration of treatment plant effluent in South Africa have been published recently.

Wilson (199) states that filtration of effluents may be necessary to remove fine humus or activated floc in certain areas. The ova of parasitic worms and cysts found in effluents can be eliminated to a very considerable extent by sand or land filtration. Using humus tank effluent containing 22 to 39 p.p.m. of suspended solids and a filtration rate of 200 gal. (Imp.) per sq. ft. per hr., Heynike and Westhof (76) obtained a removal of 83 to 91 per cent of suspended solids and 23 to 40 per cent of oxygen absorbed. Backwashing rates of 22 to 25 gal. (Imp.) per sq. ft. per min. in which the sand expanded 40 to 50 per cent appeared satisfactory. From 50 to 60 gal. per sq. ft. of filtering media were required. When air scouring was used lower backwashing rates of 15 gal. per sq. ft. per hr. appeared effective, using 60 gal. per sq. ft. of filter media.

*Combined Chemical and Mechanical*

Gibbs (52) treated the wastes from a soap plant and paper mill by adjusting the pH to an optimum value before aerating and removing sludge by flotation. Ludwig and Ludwig (108) flocculated grease from the skimmed washing of oil and paint drums by the use of alum followed by aeration. Cincinnati, Ohio, has awarded a contract (18) for the construction of the Little Miami sewage works. The plant is of the flocculation-aeration-chemical treatment type and has a 28.8-m.g.d. dry-weather flow capacity.

## Biological Filters

The Water Pollution Research Board (194) of Great Britain continued various investigations relating to the biological filtration of sewage. They studied the comparative efficiency of four trickling filters, two of which were equipped with rotary distributors that rotated once in 8 min., and the other two with distributors that rotated once in 1 min. to once in 4 min. The effluent from the filters equipped with distributors revolving at the slower rate was generally better than that from the filters dosed more frequently. The performance of two trickling filters operating in parallel was compared with two similar filters in series, except that in the latter case the effluent from the first filter passed to a settling tank before being discharged on the second filter. There was no great difference in the two effluents. However, there was a tendency for the final effluent to be slightly better when the primary filter effluent had passed through a humus tank. Settled sewage was treated on a series of small-scale filters 6 ft. deep at rates varying from 120 to 1,200 g.p.d. per cu. yd. During a portion of the test period the B.O.D. of the filter effluents after quiescent settling for 1 hr. varied from about 25 p.p.m. when the rate was 120 g.p.d. per cu. yd. to 63 p.p.m. when the rate was 1,200 g.p.d. per cu. yd.

Tomlinson and Hall (184) reported the results from experimental filters treating sewage without recirculation at rates from 100 to 1,000 g.p.d. per cu. yd. With increasing rates of application the B.O.D. in the effluent increased; above 450 g.p.d. per cu. yd. the increase was nearly linear to the rate of application. The suspended solids varied little with increasing dosages. At the higher rates of application the amount of film decreased with depth. The largest numbers of *Psychoda* were present at the middle rates of application (450 to 600 g.p.d. per cu. yd.) A very high removal of B.O.D. was obtained in the top foot of the bed. The contact time in the bed varied from 105 to 110 min. at the 100-gal. rate of application to 17 to 20 min. at the 1,000-gal. rate. From the contact times determined by salt test, the velocity constant in the monomolecular formulation of the B.O.D. removal was calculated to be about 700 times the rate of removal 68.0, in the 5-day B.O.D. test.

Studies continue to be made to determine the performance of trickling filters under various load conditions.

At the Texas Engineering Experiment Station Sorrels and Zeller (168) determined the efficiency of four filters, each 6 ft. deep and containing gravel varied in size from 1½ to 4 in. The volume of settled sewage applied to the filters varied from 1.6 to 5.4 m.g.a.d., and the B.O.D. load ranged from 450 to 1,500 lb. per acre-foot daily. Trickling filters receiving loads of 650 lb. of B.O.D. per acre-foot per day produced effluents equal in quality to filters treating loads of 450 lb. per acre-foot daily. It was estimated that loads up to 1,000 lb. of B.O.D. per acre-foot per day could be handled with moderate additional dilution in the receiving water. A decrease in efficiency was observed with loadings greater than 1,000 lb. of B.O.D.

The performance of a 6-ft. deep slag-filled trickling filter, at the University of Florida, when treating settled domestic sewage applied at rates varying from 5.0 to 20.0 m.g.a.d. and with B.O.D. loadings ranging from 1,167 to 5,470 lb. per acre-foot daily was discussed by Grantham (58). Through the entire range of loadings, the efficiency as measured by 5-day B.O.D. removals remained constant. Nitrification of the filter effluent decreased as the organic and hydraulic load increased. Considerable B.O.D. removals were observed at the 2- and 4-ft. levels in the filter.

The performance of an underloaded Aero-Filter plant was studied by Hurwitz (82). The loading on the filter was 0.92 lb. B.O.D. per cu. yd. per day, of which 83 per cent was removed. Over-all removal of B.O.D. by the plant was 92 per cent.

Mugele and Evans (125) have studied droplet size distribution in sprays and have critically reviewed several distribution equations to determine their theoretical soundness as applied to spray data. They have formulated a new equation for describing droplet size distributions in sprays. It is based on the differential equation of the Gaussian distribution, the distributed quantity being

$$y = l\,n\,\frac{a\,x}{x_m - x},$$

where $y$ is a dimensionless function of $x$, $a$ is a dimensionless parameter, $x$ is the droplet diameter, and $x_m$ is the maximum stable diameter.

Experiments with spent gas liquors made in two large-scale trickling filters were reported by Blackburn, Tomlinson, and Summers (25). The addition of the liquor in a concentration of 0.5 per cent by volume caused a significant deterioration of the quality of the effluent. Experiments with crude liquor were made on small 1-ft. diameter filters. The greatest deterioration was caused by the addition of the fraction containing thiocyanate, ammonia, and organic substances, and also by the fraction containing carboxylic acids and humic acids. Of the phenol fractions, those containing polyhydric phenols caused significantly greater deterioration than the fractions containing monohydric phenols.

Pettet and Thomas (136) report on the effect of cyanides on the treatment of sewage by laboratory-scale trickling filters. They caution against permitting sewage that contains more than 1 to 2 p.p.m. of HCN to be received at sewage treatment works. The experimental filters could be acclimatized to much greater concentrations with a removal of 90 to 97 per cent of the cyanide. However, considerable time is required to acclimatize the filters, with the result that a highly toxic effluent would be produced. Sudden flushes of solutions containing high concentrations of cyanide that may completely inhibit biological activity in the filters should be avoided. Filter effluent containing more than 0.1 p.p.m. of HCN was toxic to yearling rainbow trout.

Greeley (60) discussed the performance and cost of high-rate trickling filters, particularly with reference to their use in the United States. He

reviewed the various types of high-rate plants involving the use of high-rate filters operating ahead of lower-rate filters, single-stage high-rate filters with and without recirculation, and high-rate filters in two stages with or without recirculation. The operating results at eight municipal and one United States military establishment were discussed. Graphs were given showing the relationhip between the B.O.D. applied to filters and the percentage removal of B.O.D. by filters and humus tanks. Greeley concluded that "operating data need further study and design procedures need further development to arrive at the best over-all economy and the most desirable operating routine. Bases of design should therefore be conservative and the plant facilities should permit reasonable flexible operation."

In his studies of the difference in performance of trickling filters and secondary settling tanks during summer and winter at 9 U. S. military camps, Thomas (181) concludes that the lowered efficiency in winter resulted in the effluents having a B.O.D. approximately 20 per cent greater in winter than in summer. To attain the same degree of treatment in winter as in summer he estimates that filter volumes would have to be 43 per cent greater.

Extensive experiments were conducted by Lumb and Barnes (111) at Halifax, England, to determine the optimum period between doses of sewage applied to trickling filters. The experiments were conducted on three experimental-scale filters, each 6 in. in diameter and 6 ft. deep, and on two full-scale filters, each 65 ft. in diameter equipped with 4-arm rotary distributors. The optimum period between doses of sewage was between 4 and 9 min. "A heavily-dosed full-size filter bed fed with a distributor dosing at approximately 1-min. intervals produced a better effluent and kept in a cleaner condition—than a control bed dosed virtually continuously." Filters equipped with slowly-revolving distributors exhibited less tendency to pond than beds provided with rapidly-rotating distributors.

Grantham and Seeger (59) reported on the length of time it took trickling filters, 6 and 8 ft. deep and containing new and formerly used blast furnace slag, to mature and produce an acceptable effluent. Contrary to expectations, high efficiencies as measured by B.O.D. removal were obtained within 7 days whether new or previously used filter slag was used. To obtain nitrification in the filter took considerably longer than to secure a high B.O.D. removal. Nitrification was secured more rapidly when previously used filter slag was employed.

Rankin (143) discussed the design of trickling filters with special emphasis on the design of high-rate filters. His article includes diagrams giving the estimated performance of primary and secondary filters with various B.O.D. loadings and recirculation ratios.

In a study of trickling filter materials Schroepfer (161) investigated (a) the relationship between the surface area and shape ratio (the greatest major dimension of trickling filter media divided by the least dimension perpendicular to the long axis) of the filter materials, (b) the effect of shape ratio on the unit weight and therefore on the voids in the materials, and (c) the effect of the median particle size —for a given shape ratio—upon the surface area and voids in the materials. From a theoretical standpoint the shape factor had little effect on the surface area and, consequently, on the efficiency of a trickling filter. An increase in shape ratio resulted in an increase in the percentage of voids.

Studies (55) were conducted at Huddersfield, England, to determine the effectiveness of a special premoulded tile when used as the media in a trickling filter. Each tile consisted essentially of a ½-in. deep shallow tray with a ½-in. flat rim, standing on three

legs. The tiles were stacked one above the other to a depth of 7 ft. Although these tiles offered every hope of yielding improved results when judged by their surface area, void space, and aeration capacity, they produced an effluent inferior to that from a filter containing conventional media. The advantages of a special prefabricated tile media for use in trickling filters were discussed by Leibee and Smith (102). The tile is made in 12-in. lengths with 1-in. diameter holes extending longitudinally through the tiles. The tiles are doweled in place in a vertical position, permitting the holes to extend from the top to the bottom of the filter. This material provides 20 to 22 sq. ft. of surface per cubic foot of media. The authors recommend B.O.D. loadings as high as 3.33 lb. per cubic yard per day (5,380 lb. per acre-ft. daily).

A number of "cellular" trickling filters (23) serving from 50 to 1,500 persons have been built in Germany since 1947. The filtering medium consists of lava filter-slack contained in chemical-resistant shallow concrete trays. The sewage is distributed on the surface of the filter by concrete channels. The sewage flows through the filter from tray to tray, picking up oxygen in its descent through the medium.

In renovating one of the old trickling filters (15) at Forth Worth, Tex., it was discovered that one of the causes of its flooding and operating inefficiently was that most of the drainage tile in the bottom of the filter was broken. To prevent this condition occurring again, all heavy equipment used to spread the filter stone when the filter was rebuilt was placed on wooden mats so that the load on the tile underdrains would not be excessive. Furthermore, only carefully graded stone, with larger sizes at the bottom, was used.

Spiess (171) describes a novel method used successfully at Litchfield, Ill., to control the ponding of trickling filters. Light tire chains, 18 in. long and spaced 8 in. on centers, are fastened to two light steel angles, each of which is 8 ft. long. The angles are secured to two of the arms of a rotary distributor. As the distributor rotates, the chains drag on the filter stone and scrape off excess surface growth. By moving the angles along the distributor arms, new surfaces of the filter can be exposed to the action of the chains.

The widespread adoption of modern insecticides, such as Gammexane (benzine hexachloride) and D.D.T., is reflected in their use at widely scattered sewage treatment plants during the past few years to control trickling filter flies. Tomlinson and Muirden (183) have reported on the use of Gammexane and D.D.T. for controlling filter flies at 12 sewage treatment works in England. Treatment at rates of 1 lb. of Gammexane or 5 to 10 lb. of D.D.T. per acre appeared to be adequate for controlling *Psychoda*. The use of these amounts every two weeks, or twice these amounts every four weeks, effected reductions of 70 to 75 per cent. Slightly better results were obtained by applying the insecticide biweekly. Tests indicated that samples of effluent from certain filters treated with Gammexane or D.D.T. at rates of 1 or 10 lb. per acre, respectively, contained concentrations of insecticide toxic to trout. McLachlan and Hogg (120), as a result of their tests at the Cydna sewage treatment works serving Johannesburg, South Africa, conclude that Gammexane "in suitable formulation offers the most convenient, effective, and economical treatment for the control of *Psychoda*" which they had experienced. In discussing the above-mentioned tests, Walmsley indicated that he had controlled *Psychoda* at the sewage treatment works serving the Modderfontein dynamite factory by (a) improving sedimentation to reduce the load applied to trickling filters, (b) using chloride of lime, (c) recirculating humus tank effluent, and (d) using Gammexane. He found the

use of Gammexane the most effective, least damaging, and most convenient of the four methods tried. Livingston (105) reports the successful use of Chem-Larv, a newly developed insecticide the chemical composition of which is not revealed, to control *Psychoda* flies at the sewage treatment plant serving Ridgewood, N. J. The recommended dosages are 16.7 lb. and 8.8 lb. per acre-foot to low-rate and high-rate filters, respectively, to be applied over a 2-hr. period.

Daviss (37) discussed the remodeling and the enlarging of the trickling filters and humus tanks at the Minworth sewage treatment works of the Birmingham, Tame, and Rea District Drainage Board, in England. Experiments conducted in conjunction with the Water Pollution Research Board indicated that "by having double filtration with a 24-hr. interchange of primary and secondary filters the Minworth settled sewage would give a consistently satisfactory effluent with a B.O.D. of less than 20 p.p.m. when dosed continuously at a rate not exceeding 250 g.p.d. per cu. yd. of medium with settlement of the primary effluent." At Minworth, filters operated on recirculation did not remain in as good condition as those on alternating double filtration. For design purposes a loading of 160 g.p.d. per cu. yd. of total medium on the average dry-weather flow has been adopted, with a peak loading of 240 g.p.d. The conversion of the sewage works is being made in stages. As each section is completed, it will be put into operation immediately. The filter area will be divided equally between primary and secondary filters, with humus tanks for each stage.

What is perhaps the deepest trickling filter on record (3) went into operation during the summer of 1950 in Cumberland Falls State Park, Ky. The filter is 14 ft. in diameter and 35 ft. deep, with a rated loading of 400 lb. of B.O.D. per acre-foot per day.

Liebmann (104) reported that in underloaded filters there is a definite zonal distribution of organisms. With increasing loads polysaprophytic and mesosaprophytic colonies move towards the bottom of the filter. Bacteria-eating organisms exist near the top, whereas predators live near the bottom. There is also a horizontal gradation of organisms, which is more uniform when the sewage is weak. In flooded trickling filters practically only bacteria and protozoa exist in the slime.

The behavior and distribution of larger worms in trickling filters was studied by Terry (178). Two types of earthworms were found, namely, *Lumbricus rubellus* and *Eisenia foetida*. The worms are most abundant in beds of smaller-sized media and in the surface of filters in autumn and winter. In most filters little is seen of worms at the surface of the beds and the only indication of their presence is given by the large numbers washed out into humus tanks. They show an aversion to light, but migrate nocturnally to the surface of the bed. Experiments showed that a filter artificially colonized with worms gave a higher efficiency of purification than the control. The seasonal variation of the worms is attributed to the effect of the grazing activities of other members of the fauna, which reduce the food for the worms. The worms perform a valuable role in the scouring of small filters. It is estimated that worms could deal with 3 cu. ft. of film per week. The worms are considered valuable members of the fauna of filter beds, especially for small-sized media, and complement the grazing activities of insect larvae.

### Activated Sludge

Laboratory experiments by Keefer and Meisel (89) have shown that best activated sludge performance was obtained at pH 7 to 7.5, although removals of oxygen consumed, suspended solids, and bacteria were very good at pH values ranging from 6.0 to 9.0. Removals of oxygen consumed averaged about 43 per cent at pH 4.0 and 54

per cent at pH 10.0. At pH 5.0 to 5.5 the organisms seemed to become adjusted to the acidity and after a few weeks the removal of oxygen consumed increased from 48.3 to 82.1 per cent. Raising or lowering the pH on either side of neutrality greatly improved the sludge index.

Heukelekian, Orford, and Manganelli (75) showed that sludge accumulation in the activated sludge process is influenced by the concentration of aeration tank solids, the sewage strength in terms of B.O.D. or suspended solids, and the relationship between sewage strength and the solids concentration in the aeration tank. In general, the greater the concentration of activated sludge, the less the accumulation of suspended solids.

Helmers *et al.* (69) conducted laboratory experiments on the stabilization of a number of industrial wastes with activated sludge from the standpoint of determining the nutritional requirements under various conditions of loading. The wastes studied (cotton kiering, rag-rope, and brewery wastes) were added to sewage at different volumetric dosages. All these wastes were found to have nutritional deficiencies. At low concentrations the deficiencies could be met from the nutrients in sewage. At high loadings, if the deficiencies were not supplemented artificially, the sludge produced had poor settling and dewatering characteristics.

Horwood *et al.* (80) isolated six floc-forming organisms from activated sludge, which under aseptic conditions of aeration and from sterile nutrient solution were able to produce good clarification and B.O.D. reduction and activated sludge-like mass. These organisms were not identified as *Zooglea ramigera*, but apparently belonged to *Enterobacteriaceae*.

According to Pillai (137), the protozoa *Epistylis* flocculates sewage solids effectively. These organisms are largely responsible for the color, composition, and activity of the activated sludge and are the main cause of the difficulty in drying the sludge. Horasawa (79) reported that the numbers and activity of activated sludge protozoa are affected by the numbers of bacteria in the sewage. Artificial additions of pure culture bacteria increase the numbers of protozoa in the activated sludge. About 300 to 400 bacteria per protozoan are removed by ingestion in 6 hr. The activated sludge surfaces are regenerated by digestion of bacteria and organic matter after ingestion and not by exo-enzymes.

According to Pasveer (134), the oxygenation of water in a tank equipped with rotary brushes takes place in the close vicinity of the brushes and especially in the mass of foam thrown up.

Pasveer (135) considers the oxygenation capacity of activated sludge very important from the standpoint of purification. It would be expected, therefore, that increasing the oxygenation capacity would increase the purification capacity. Actual experiments by the author at a small activated sludge plant furnished with rotating brushes showed that by increasing the oxygenation capacity 4 to 5 times, by increasing the diameter of the brushes and the speed of revolution, he was able to obtain loadings equivalent to 220 lb. B.O.D. per 1,000 cu. ft. of aerator capacity with a mixed liquor suspended solids of 4,000 to 4,500 p.p.m. and obtain excellent effluents.

Roe has reviewed the use of air diffusion in the activated sludge process (148) and the subject of pre-aeration and air flocculation (147). He pointed out that the advantages of pre-aeration are prevention of septicity, removal of odors, improved flocculation of solids, increased grease removal, and a general improvement of the sewage to make it more suitable for subsequent treatment. Kappe and Neighbor (86) also have discussed the advantages of pre-aeration. They believe that present standards of design call for at least 30 min. of aeration, using

a minimum of 0.1 cu. ft. of air per gallon of sewage, or an amount necessary to maintain tank circulation. About 15 to 30 days of pre-aeration seem to be required before there is improvement in the removal of B.O.D. and suspended solids. Whitney (198) found that the use of pre-aeration ahead of the activated sludge units produced a 10 to 20 per cent removal of B.O.D., leveled off the load on the aerators, and increased the over-all B.O.D. removal.

Impingement aerators, which consist of an air header on the bottom and a parallel recirculated liquor header over the air header, were described by Sperry and Walker (169). Air is released through large (7/32-in.) orifices. Recirculated liquor discharges downward against impingement dishes. Impingement of liquor on the dishes causes cavitation, physical contact, and shearing between the air and liquid immediately above the dishes. Extremely fine bubbles may be obtained, but usually it is only desirable to produce bubbles comparable in fineness to those from diffuser plates with a permeability of 30. Each impinger is rated at from 6 to 10 c.f.m. of air. Minimum air requirements to keep activated sludge in suspension are approximately 5.0 c.f.m. per 1,000 cu. ft. of aeration tank volume.

Pilot plant studies using the Aero-Accelator have been described by Eidsness (43). The equipment consists of an aeration and a settling compartment in one unit. The settled solids are recirculated through the aeration compartment and large bubbles of air are broken up and dispersed mechanically by a revolving multi-blade rotor. Results from Sioux Falls, S.D., and Austin, Tex., indicated B.O.D. removals of 85 to 90 per cent with 2- to 4-hr. detention and using from 0.5 to 1.38 cu. ft. of air per gallon of sewage. Ullrich and Smith (187) have discussed pilot plant studies using the Biosorption process. Essentially, the process consists of three distinct steps: (a) Intimate mixing of the activated sludge with raw sewage by aeration for 15 to 30 min. to allow adsorption of organic material; (b) separation of the sludge by sedimentation; and (c) regeneration of the sludge by aeration for about 90 min. to permit its re-use in step (a). Results indicate that effluents averaging 14 p.p.m. suspended solids (93.8 per cent removal) and 20 p.p.m. B.O.D. (92.5 per cent removal) can be obtained.

According to Edmondson (42), about 60 per cent of the Sheffield, England, aeration plant has been improved by installation of new paddle wheels fitted with triangular blades rotating at 30 r.p.m. When completely installed, the capacity of the plant will be increased from 18 m.g.d. to 30 m.g.d. (Imp.) The cost of aeration has been reduced about one-third.

Increase in the B.O.D. of the settled sewage from 77 to 106 p.p.m. has increased the air requirement at the Wards Island plant of New York City to about 0.75 cu. ft. per gallon and has made the use of high-rate activated sludge, with its saving in air, attractive. Torpey and Chasick (185) report that for several months about 110 m.g.d. of settled sewage were treated in this manner, using 0.4 cu. ft. per gallon of sewage. The effluent contained about 25 p.p.m. of suspended solids and 30 p.p.m. of B.O.D. Lengthening the flow path in the final tanks has improved operation at both the Wards Island and Tallmans Island plants in New York City.

Wirts and Ausflug (200) believe that it is better to thicken aeration tank effluent than excess sludge at the Cleveland (Ohio) Easterly plant. A relatively constant proportion of the aeration tank effluent is settled in two final tanks, at overflow rates of about 400 g.p.d. per square foot. For the past seven years the thickened sludge has averaged 2.49 per cent solids and the effluent 26 p.p.m. suspended solids.

Kirsch (94) stated that, at the Cleveland Southerly plant, waste activated sludge is thickened in two Dortmund-type tanks. These are operated on a fill and draw basis, with an average sedimentation period of 7.5 hr. The thickened sludge averaged 2.7 per cent solids.

Thomas (181) has reviewed the literature on sewage treatment in low-temperature areas and found that activated sludge aeration units had less difficulty with freezing than trickling filters. The effect of low temperature can be counteracted, in a measure, by increasing either the aeration tank solids or the detention period.

Lamb (99) has discussed the design of small activated sludge plants using diffused air and presented curves showing the aeration periods, the air required for various strengths of sewage, and the most economical tank dimensions.

New developments, particularly Biosorption, step aeration, and high-rate activated sludge, were discussed by Kalinske and Gillard (84).

Continued interest has been shown in the cleaning of air diffusers. At the London County Council's Northern Outfall works Bruce and Stevenson (29) found that diffuser plates clogged by rust, grease, microbial slime, hard-water scale, and sooty materials were brought back nearly to their original permeability by treatment with 50 per cent caustic soda followed by commercial hydrochloric acid diluted with an equal volume of water. The trays containing the plates were removed from the aeration channels for treatment. The cost of chemical treatment was about one-fourth of that for burning. They also reported that high humidity in the air caused an increase in the back pressure at the blowers. If the original humidity was more than 67 per cent of saturation, condensation might be expected to occur in the system. In extreme cases, as much as 0.25 lb. of water might be condensed from each 1,000 cu. ft. of air compressed. Experiments are in progress using plastic tubing (instead of galvanized wrought iron) downpipes to reduce corrosion. Long (107) stated that the diffusers at the Gravesend sewage disposal works are also cleaned successfully with caustic soda and hydrochloric acid.

Samson (155) has cleaned sintered alundum plates by heating them directly over a gas flame. However, the plates cracked very easily. Heating in a gas-fired oven, followed by slow cooling and wire brushing, was also successful in cleaning clogged plates. French (49) reported that when clogged diffuser plates at Wards Island were cleaned by spalling and jet washing every 4 to 6 months, blower pressures could be kept below 7.5 p.s.i. The spalled plates have now passed more than 4,500,000 cu. ft. of air each, or more than the amount passed before spalling.

## Chlorination

The fourth Manual of Practice of the Federation of Sewage and Industrial Wastes Associations published in 1951, was titled: "Chlorination of Sewage and Industrial Wastes." It constitutes a complete factual report on present-day chlorination practices (35). Also, a committee of the Federation of Sewage and Industrial Wastes Associations has reported on problems involved in the availability and distribution of chlorine for sewage treatment purposes. Producers of chlorine are now required to supply chlorine for water and sewage treatment needs. The committee concludes that problems of container size, and of unfavorable local purchase practices are critical; they are not easily rectified and should receive careful study directed toward their solution (34).

The efficiency of chlorination for destroying sewage bacteria generally has been measured in terms of percentage reduction; but the number of

coliform organisms varies from 10,000 to 1,000,000, and the safety of a chlorinated effluent must be based on the actual number remaining in the effluent as discharged. Laboratory studies have been made to formulate the chlorine dosages required to obtain stipulated residual coliform counts. Fresh and stale sewage, and trickling filter and activated sludge effluents were investigated. The factors of contact time, dilution of sewage, initial number of coliform organisms, and concentration of chlorine solution applied, were all related. Most significant results of the investigation are: chlorine dosage cannot be used as the basis of achievement of stipulated residual coliform organisms; in settled sewage the amount of chlorine required for a 30-min. contact time is less than one-half of that required for a 5-min. contact time; dilution of sewage with water in the ratio of 1:4 decreases the chlorine requirement by one-half with a 5-min. contact time and by one-fourth with a 30-min. contact time (73).

Papers presented before the University of Michigan School of Public Health reviewed important applications of chlorine in treatment of sewage and industrial waste. The first paper (124) discussed the chemistry involved in disinfection, in B.O.D. reduction, and in the destruction of oxidizable chemical substances in wastes. The second paper (193) presented a series of practices which make chlorination so significant a tool in stream sanitation. The regulation of applications for improving sewage effluents and for treating industrial wastes were reviewed in detail.

Bacteriological studies made at two sewage treatment plants verify the greater efficiency (in disinfection) of good chlorine mixing facilities, and demonstrate that (with low chlorine residuals) contact time plays an important role. For a 50 per cent compliance with a stipulated effluent standard of 2.5 coliform organisms per ml., an ortho-tolidine residual of 0.2 to 0.5 p.p.m. will be adequate using a 15-min. contact time; for an 80 per cent compliance at the same residual, a 30-min. contact time is required. Amperometric residuals required are higher than ortho-tolidine residuals, although a definite correlation is considered to exist (72).

Plant operations have been investigated to determine the degree of distribution of chlorine in contact tanks where various types of mixing devices are provided. Where no special mixing compartments exist, chlorine distribution is not uniform. Vertical channels or relatively shallow mixing compartments (with high turbulence) ahead of the contact tank provide adequate mixing. Mechanical mixing devices, it is concluded, are not required where hydraulic mixing is satisfactory (71).

Studies by the British Water Pollution Research Laboratory, involving treatment of waste waters from a paper mill, reveal that percolating filters can operate successfully if the applied waste contains up to 12 p.p.m. combined residual chlorine (8).

Adequate treatment to meet standards of the Interstate Sanitation Commission in reducing pollution of the Hudson River may be accomplished by modern primary treatment and chlorination. The new plant at Croton, N. Y., is an example of such treatment (26). The new Hyperion plant of Los Angeles, Calif., uses the activated sludge process, but finds pre- and post-chlorination desirable adjuncts (24). The sewage treatment plant at Wooster, Ohio, incorporates chemical treatment during periods of the year when the receiving stream cannot assimilate the effluent from treatment by plain sedimentation. For several years it has been found possible to maintain a dissolved oxygen concentration higher than 5 p.p.m. by the use of chlorine as the first step beyond plain sedimentation; the chlorine is applied also for odor control, disinfection, and stream stabilization (36). In the

Golden Gate Park at San Francisco, an activated sludge sewage treatment plant purifies sewage to provide water for maintaining the level of lakes in the park. Since 1947, the effluent has also been pumped to the park reservoir and may enter the waterworks distribution system. Chlorination is carefully controlled and a residual of 2.0 p.p.m. is maintained at the end of a contact tank which provides a minimum period of 20 min. for disinfection (115).

## Sludge Digestion

### *Theory and Mechanism*

Results of a comparative study of types and concentrations of lower volatile acids produced during digestion of seeded, unseeded, and limed fresh solids were reported by Kaplovsky (85). Only three volatile acids (acetic, propionic, and butyric) occurred in measurable quantities. These occurred in similar amounts in all three sludge conditions studied, but at different rates. Slowly digesting fresh solids mixtures exhibited similar accumulations of acetic and butyric acid. These acids increased rapidly to a maximum concentration and remained at that level until more favorable conditions for digestion prevailed. In all three types of solids studied, propionic acid appeared in two separate peaks, with no accumulation in between. The first peak occurred early in digestion; the second, during the last stage of decomposition of the solids. Liming increased the rate of hydrolysis, but did not alter the manner of decomposition.

Two new species of methane-producing bacteria were isolated and studied by Stadtman and Barker (172). One, *Methanobacterium suboxidans,* converts valeric acid by means of beta oxidation to propionic and acetic acids. In a similar manner, butyric and caproic acids are oxidized quantitatively to acetate. The other organism, *Methanobacterium propionicum,* oxidizes propionic acid in such a way that the carboxyl carbon gives rise to carbon dioxide and the alpha and beta carbons yield acetate. The methane formed in these fermentations is derived entirely from carbon dioxide. The mechanism of these fermentations was studied by tracer experiments. Using tracer technique the same authors (173) showed that *Methanosarcina* forms methane from the methyl group of acetate and from methyl alcohol, rather than from carbon dioxide in the fermentation of these substrates.

Heukelekian and Berger (70) reported on the occurrence and detection of alcohols, acetone, and acetaldehyde in sewage undergoing anaerobic digestion. They refer to these substances collectively as "volatile neutrals," to differentiate them from volatile acids.

The nature of methane producers, notably *Micrococci* and *Sarcini,* was discussed by Schlenz (159). He pointed out that the rate of sludge digestion is directly related to the abundance of these forms, and that a definite relationship exists between bacterial flora and successful digester operation. Eckenfelder and Hood (41) showed that anaerobic organisms function best at negative oxidation-reduction potentials. Sulfate added to a digesting mixture depressed the reductive intensity level from a range of 0 to $-100$ millivolts $E_h$ to a range of $-125$ to $-175$ millivolts $E_h$. The result was improved digestion, better gas production, and the elimination of "lay-over" sludge. Sludge with a $+200$-millivolt O–R potential showed a low pH and high volatile acid content. Rapid anaerobic decomposition of cannery wastes and of a textile waste high in acetic acid occurred after proper treatment had changed the O–R potential from positive to negative, thus permitting the proper functioning of the enzyme systems of the organisms.

### *Operation and Efficiency*

Schaetzle (157) listed the specific factors in sludge digestion as: control of operation, digestion balance, pH

control, liming, volatile acids, foaming, scum formation, supernatant liquors, and use of seeding with pure cultures. Operational procedures in sludge loading and withdrawals were reviewed by Schlenz (159), along with the usually accepted environmental conditions within the digester. The optimum temperature range of 90° to 95° F. was verified, but to be effective it was noted that temperature must be uniform through the depth of the tank. Temperature must also be controlled, as *Micrococci* are quite sensitive to rapid variations in temperature.

Kirkwood (93) made recommendations for operational procedures if cold digesters are to be successful and Thomas (181) reported failures of Imhoff tanks due to insufficient heat in the sludge compartment, concluding that sufficient data are available to predict the performance of digestion tanks at any reasonable temperature or loading.

In maintaining the desired pH range of 6.8 to 7.2, Schlenz (159) believes that lime has been greatly misused and that the proper pH will result from proper operation without liming. Some difference of opinion among operators was reported (9) in this matter. In one special case (116), engineers recommended the introduction of carbon dioxide into digesters to lower the pH of a mixture of industrial wastes and sewage.

The importance of seeding raw solids entering the digester was stressed by Scheller and Fynn (158) who found that introducing raw sewage at a single point rendered a considerable portion of the digestion tank more or less dormant. Arthur (16) described an expansion in plant capacity at Denver, Colo., in which raw sludge is inoculated or seeded with pre-digested sludge from the supernatant liquor tank. A patent was granted (197) for improving anaerobic activity in a septic tank by adding, twice yearly, an 18-oz. charge of finely powdered mixture consisting of 1 part of sawdust, 5 parts of dry yeast, and 9 parts of wheat flour, by weight.

Experiments with recirculation in a two-stage digestion system were reported by Murray (126). Detention periods of 36 to 48 days were used. Seeding with digested sludge gave slightly improved performance of digesters when detention was about 40 days, but no effect was observed in 36 days, and 48 days detention resulted in decreased efficiency. He concludes that detention period is important, but that recirculation is not comparable in effect to recirculation in aerobic processes. Digestion beyond 30 days was considered by Schlenz (159) as not generally economical. He reported that sludge is considered sufficiently digested when 40 to 50 per cent volatile matter remains. A curve shows the relationship between per cent volatile solids in raw sludge and per cent reduction in volatile solids when sludge is considered digested. Finished sludge in various American and British cities contains from 38 to 50 per cent volatile matter.

Wirts and Ausflug (200) pointed out the desirability of reducing the volume of excess activated sludge by concentrating before mixing it with primary sludge for digestion. On the other hand, troubles with strong sludges were reported by the Research Council of Israel (12). Analysis of crude sewage showed B.O.D. values several times greater than raw sewage in the United States. A report covering the first months of operation of an Imhoff tank showed no B.O.D. reduction being accomplished, probably because of the simultaneous oxidation of ammonia, hydrogen sulfide, and organic matter.

Improvement of the operation of a sludge digester by the use of Cloroben was reported by Holtz (77). Operational difficulties included black supernatant with hydrogen sulfide odor, poor dewatering quality of sludge, low-grade gas in small quantities, corrosion problems, and excessive liquid in traps.

Cloroben was added to make 100 p.p.m. in the digester; thereafter, 100 p.p.m. was added daily with the result that the troubles disappeared. Difficulties soon reoccurred when treatment was discontinued.

*Gas Production*

The economic value of sludge gas to the City of Johannesburg, South Africa, was reported (65). An agreement was drawn up whereby the city will furnish a manufacturer of explosives with 300,000 cu. ft. per day of digester gas containing 62 per cent methane, at a price of 25¢ per 1,000 cu. ft.

A relationship between gas production of digesting sludge and the food consumed by humans was reported by Kehr (90). As a result of the poor quality of food in Germany after World War II, it was no longer economical to utilize gas from digesters as a motor fuel in cities with fewer than 20,000 inhabitants. Before the war the economic minimum size of city was 10,000 population. In modernizing a 46-yr. old sewage works at Wuppertal-Buchenhofen, a turnip-shaped digester 75 ft. in diameter by 78 ft. high was constructed (4). Gas produced amounted to 0.53 cu. ft. per capita per day and had a methane content of 65 per cent. Loesch and Ruppercht (106) reported that 0.5 per cent garbage in sewage solids reduced the gas production 7.7 per cent; 90 per cent garbage reduced gas by 89.3 per cent. These reductions were due to the presence of sulfates. In concentrations of 500,000 per gram of digested sludge, sulfate-reducing organisms produced 0.35 p.p.m. hydrogen sulfide in sewage sludge; 4.2 p.p.m. hydrogen sulfide in sewage sludge plus 5 per cent garbage; and 8.0 p.p.m. hydrogen sulfide in sewage sludge plus 10 per cent garbage. Gas production was reduced by 18.2 to 22.1 per cent by 0.1 to 0.2 per cent calcium sulfate. Ashes in garbage contain up to 17.3 per cent sulfates; hence, for successful digestion of garbage with sludge, ashes must be excluded.

A simplified method for calculating gas production, designed for training operators, was introduced by Waggoner (190). Determinations of ash percentages of raw and digested sludge are made and the percentage reduction of volatile matter during digestion is read directly from a graph. Gas production is then calculated.

*Effect of Wastes*

The effect of garbage on sludge digestion was reviewed by Haseltine (68). Digestion of garbage alone produced acid conditions and pH too low to permit digestion. The nitrogen content of garbage (1.5 per cent of volatile matter, as compared to 4 per cent in sewage) was likewise too low for good digestion. Digestion with sewage sludge was successful in ratios of 1.5 to 3 garbage to 1 sludge. Methods of operating digesters involving garbage and sewage sludge, as well as results obtained, were described.

Sludge from industrial sewages containing metallic and other wastes may render phosphate unavailable, or may be harmful to digestion in big doses (11). Mitchell, Cassanos, and Okun (122) reported copper and chromium in sewage in sufficient quantities to be intolerable to sludge digestion. Consequently, a non-biotreatment was recommended.

A case of the upsetting of digesters by phenol wastes was reported by Lebetkin (101). Waste tars from a gas plant scrubber undergoing cleaning operations reached digesters at a time when digestive health was already poor. Phenolic odors developed in the digester at once and continued for about two weeks. Gas production began to drop and declined 72 per cent in 7 days. In 4 days alkalinity and pH dropped, due to inactivity of "digestive agent" by wastes.

Mann (114) found anaerobic digestion of penicillin wastes possible after removal of interfering formaldehyde.

*Design*

For unheated digesters, Kirkwood (93) suggested 5 to 7 cu. ft. per capita as required digester capacity when recommended operational procedures were followed. Schlenz (159) presented a table for heated digesters showing good results with loadings from 2 to 4.71 lb. volatile matter per cu. ft. of digester.

New processes were described by several authors. Mohlman (123) reported some development of high-rate anaerobic digestion for use in treating organic industrial wastes. The work is still experimental and the process costly.

## Sludge Disposal and Utilization

The announcement during the past year of the discovery of vitamin $B_{12}$ in sewage sludge is one of considerable interest and importance (78). The vitamin was isolated during biological oxidation tests on dairy wastes by the U. S. Department of Agriculture. Later its presence was determined in activated sludge at a municipal plant.

Application of an old principle is the Laboon sludge handling process (97), wherein pre-heated raw sludge is stored in tanks at 95° F. for not over 5 days, resulting in carbon dioxide production and flotation of the solids. The concentrated sludge, averaging 20 per cent solids, is handled by a Moyno pump, a unit capable of moving such materials as cold cream, plaster, or potato salad. At Pittsburgh's Allegheny County treatment plant, now under design, it is planned to burn the sludge so processed in a multiple-hearth incinerator using cheap coal for auxiliary fuel and without prior vacuum filtration. To remove settled sludge, a collecting mechanism is being incorporated in the sludge concentration tanks. It is claimed that the concentrated sludge can be vacuum filtered without chemicals, but such considerations as cloth blinding have probably not been fully investigated to date. Another possibility for the process is the introduction of such concentrated raw sludge to methane-producing digestion tanks with possible large savings in the size and number of digesters required.

From a study of the economics of various methods of sludge disposal in primary plants, Laboon (98) concluded that on the basis of 1950 prices and Pittsburgh fuel costs, concentration of raw sludge by digestion for a short period and consequent gas flotation, followed by incineration, was the most economical method of sludge disposal in all but the extremely small treatment plants.

Leibee and Smith (103) state that for small communities (less than 5,000 population) a simple, low-cost, odorless, positive form of sludge treatment consists of adding ferric chloride to the raw sludge and applying the conditional sludge to sand beds, where it dewaters in about 6 to 24 hr. In the 10 plants studied (averaging more than 2,500 p.p.m. of ferric chloride) bacteria are greatly reduced by such treatment, offering protection to the public health "at least equal to that offered by the digestion method." A major disadvantage of this method is that the sludge must be hauled and disposed of on farm land at intervals not exceeding 10 days.

Late in 1950, Houston, Tex., completed a new sludge utilization plant at a cost of $1,367,171 designed to vacuum filter and flash-dry raw primary and raw activated sludges up to 71 dry tons per 24 hr. (186). Favorable year-around markets for the dried sludge are available locally from rice growers and truck gardeners. Peak sludge loads and emergency disposal can be handled by utilizing existing sludge lagoons.

Battle Creek, Mich., reported during the past year on the production of a new product (119). From 1944 to

1950 the sludge at this plant was vacuum filtered and heat dried, the product being sold under the name of "Battle Creek Plant Food." Increased freight rates and labor costs near the end of this period resulted in a financial loss in its production. A private company has taken over the sludge disposal facilities of the city and is producing about 100 tons per month of D-P-M, made from a grey mud-like by-product of penicillin manufactured near-by by the Upjohn Co. Disposal of this material was proving quite a problem before it was shown that the dried prepared product, D-P-M, was a valuable antibiotic when added to animal and fowl feeds. Battle Creek reports more financial return from the sale of sludge gas, formerly wasted, than was realized before from the sale of fertilizer, and the company removes and stockpiles the plant's sludge cake dried on sludge beds used before the vacuum filter and drier facilities were built.

Haseltine (67) has suggested the terms "gross bed loading" and "net bed loading" as applied to sludge drying bed performance, and has developed formulas for computing these loadings. Next to temperature, he finds the solids content of the sludge applied to the beds the most important factor influencing bed performance, the moisture of the sludge removed from the beds being next in importance. Data from a number of plants and detailed studies at Grove City and Butler, Pa., show that application of the formulas indicates optimum dosing depths as well as the influence of chemical coagulants on drying rates.

A comparative study of vacuum filter cloths was made by Joseph (83). A number of cloths were tested with a filter leaf apparatus. Results indicated that with the cost of the cloth considered, a cotton cloth with nap rated best, plain wool second, and cotton twill third. Cloth durability is also an important consideration which can only be determined under extended use. Joseph does not state either the kind or quality of the sludge tested, which together with other variables encountered in actual practice have a considerable bearing on filter cloth performance.

In South Africa, Keller (91) reports that helminth ova are not killed by ordinary digestion and drying of sludge. Thermophilic digestion destroys them or raw, digested, and dried sludge exposed to 55° C. for 2 hr. will inactivate them. Possible parasitic ova problems in the United States seem limited to the warmer regions so far as is now known.

A report by the British Ministry of Agriculture and Fisheries (11) on the agricultural use of sewage sludge, published in 1948, concludes that the crop-producing power of sludge taken from drying beds is less than that of an equal weight of farmyard manure. It is claimed that the lack of coarse fibrous ingredients in sludge cake produces less pronounced physical effects on the soil. Digestion and shredding or mechanical drying was found, however, to improve the physical condition of sludge and the availability of its nitrogen. The composting of straw with sludge was found to produce a product having better physical effects on the land. Other conclusions from the report confirm findings already reported in the United States.

Knight (95) suggests 1½ parts of sludge (dry basis) to 1 part of straw for composting, with occasional land tiles under the heaps to allow aeration. Straw and sludge are alternated in layers and soaked with water until a height of 6 ft. is reached.

The physical condition and the moisture content of sewage sludge and the high carbon-nitrogen ratio of domestic refuse militate against the use of these waste materials separately for agricultural purposes. When these two substances are mixed to form a compost a valuable manure is produced according to Wylie (201). When temperatures of over 140° F. are obtained in the compost pile, humus is formed

with less loss of organic matter and with higher nitrogen content than when lower temperatures prevail. Highest temperatures are reached when the wastes contain a high proportion of carbonaceous matter and the moisture and the aeration within the compost are proper. Alternate layers of carbonaceous wastes with fine dust, wet sewage sludge, and ground limestone are used to a total depth of 3.5 ft.

### Mechanical Equipment

According to data from a survey conducted jointly by the U. S. Labor Department's Bureau of Labor Statistics and the Public Health Service (5), material costs represent approximately 40 per cent and labor a little over 30 per cent of the cost of building new sewage collection and treatment works. The balance is for overhead, profit, and charges for the use of construction machinery. Approximately $160,000 per $1,000,000 of expenditures for sewage treatment plant construction was for machinery and equipment to operate the works, whereas for sewage collection lines the expenditures for this item were only $42,000 per $1,000,000. The data were obtained from engineers' reports on a sample of 200 projects built in 1948, 1949, and 1950.

Continuing the series of articles, begun in 1950, on the application and operation of mechanical equipment in sewage treatment processes, Flood (48) discusses vacuum filtration of sludge, multiple hearth furnaces, and flash drying and incineration. Carter and Karassik (30) present a comprehensive review of the basic factors to be considered in the selection and application of centrifugal pumps. The problems involved in the rational design of sewage pumping stations are discussed by Hands (66) and Kennedy (92). Oesterle (128) found the use of "Hydroseal" rubber-lined pumps to be more advantageous than metal pumps in the pumping of a highly abrasive waste sludge resulting from the grinding and polishing of plate glass. The design features, pumping schedules, and station layout for the city-county sewerage project planned for Wilmington, Del., are discussed by Vollmer (188). To provide for a range in flow of from 25 to 165 m.g.d., the optimum combination proved to be five identical pumps each connected to two-speed motors. Each two-speed unit will handle 25 m.g.d. at low speed and nearly 50 m.g.d. at high speed. Pumps will be protected by mechanically cleaned trash racks with 4-in. openings. Immediately following the trash racks, mechanically cleaned screens with 1-in. openings will be installed. Screenings will be comminuted and returned to the wet well. Studies showed that if comminutors were used directly in the sewage stream instead of screens, more units and greater cost would have resulted. Electrical power for the pumping station will be furnished from the sewage treatment plant with two dual-fuel engine generators. Operation of the pumping equipment will be by remote control from the sewage treatment plant.

The electrical equipment installed at the new 26th Ward sewage treatment works at New York City is discussed by Barbi (19). The principal power supply is obtained from three 1,125-kv.-a., 4,160-v., 300–r.p.m. generators driven by dual-fuel engines. These will normally operate on sewage gas, with fuel oil for ignition and supplementary energy when required. Kass *et al.* (87) present cost data on operation and maintenance at New York City's sewage treatment plants. The repair and maintenance of mechanical and electrical equipment at these plants are also discussed. The cost of operation and maintenance per m.g. treated rose in 1950, and is attributed to the general rise in labor and material costs, coupled with the fact that there was a decrease in sewage flow because of water conservation.

General information on the operation and maintenance of electrical

equipment in waste treatment plants is discussed by Walker (191) and Kuhl (96). Sandel (156) reviews the problems involved in providing protective coatings, against corrosion, to materials of construction and equipment in waste disposal plants.

The regulatory equipment system to protect four blowers, with a total capacity of 49,000 c.f.m. at Philadelphia's new Northeast sewage works, together with the design and operation of valves and meters on the blower intake and filter system, and the air conditioning equipment for the blower and motor room, are discussed by Grandinetti (57).

Evaporation equipment in use at the Oak Ridge National Laboratory and the Knolls Atomic Power Laboratory are discussed by Browder (27) and McCullough (117). At the Knolls Laboratory a forced circulation type of evaporator system having a capacity of 500 g.p.h. has produced decontamination factors of $10^7$ from evaporator heel to condensate. The miscellaneous dilute radioactive units were highly concentrated in a safe and effective manner at a direct cost of approximately 3¢ per gallon. Indirect and amortization costs are about 8¢ per gallon additional. Volume reduction of about 60 to 1 is accomplished in the evaporator, constructed with used equipment, at the Oak Ridge plant. Evaporator foaming has produced an operating problem at this plant.

Bass and Evans (21) review some applications and present operation results of flocculation and sedimentation equipment in the treatment of various industrial wastes. Guillot (62) discusses the vacuum filter and its application in pickle liquor disposal. Among the articles which describe equipment for pre-aeration, aerated grit chambers, aeration, and air flocculation are those by Roe (147), Kappe and Neighbor (86), Sperry and Walker (169), and Eidsness (43). The instrumentation and equipment for an automatically operated demulsifying, decanting, and filtering plant to treat oil-polluted waters is described by Oesterling (129).

Stone and Teeple (175) present detailed design drawings of apparatus with provisions for simultaneously obtaining a bacteriological sample, B.O.D. sample, D.O. sample, and extra fluid for a 1-gal. chemical analysis sample. How to make an emergency stream sampler using Mason jars is described by Fuess (50). Gerard (51) describes a simple weir cleaner consisting of a coil chain riding on the top of the weir of a circular tank. Olson *et al.* (130) have designed and constructed a unit for drying water suspensions of algae. Thomas *et al.* (182) describe an integrating water sampler consisting of a vacuum can with a specially designed needle valve inlet to a sample collection bottle. The suction, created by evacuating the can, is relieved by a slow air leak, through the needle valve, which causes water to be drawn through an inlet tube into the bottle. The rate of intake can be adjusted so as to give collection times ranging from a few minutes to 36 hr. The sampler should prove of value in stream survey and lake pollution investigations, and in other studies where composite samples are needed to give a more accurate picture of conditions than are obtainable with grab samples.

## Dual Disposal

Cohn (32) discusses the history, the early objections to, and the present status of dual disposal. Studies in Detroit (131) on the effect of introducing ground garbage into sewer systems showed that about 25 per cent of the dry solids of garbage goes into solution or nonsettleable suspension. If 100 per cent of a community's garbage is ground and introduced into the sewer system, the chlorine demand of the effluent of the primary sedimentation process may be increased 0.12 p.p.m. (about 4 per cent) as a maximum, the B.O.D. will be increased by 20 to 25 per cent, and the solids by

about 50 per cent. In studying the effect of ground garbage in the Sanitation Districts of Los Angeles County, Rawn (145) selected a new housing project with 4,000 population furnished with individual garbage grinders. By comparing the per capita contribution from this area with a strictly residential sewage from a neighboring city without garbage grinders, an estimate of the increase in loading due to ground garbage was obtained. This amounted to a per capita increase of 0.047 lb. (44 per cent) of suspended solids, 0.054 lb. (52 per cent) of B.O.D., and 0.028 lb. (147 per cent) of grease. Sewer inspection showed a number of obstructions due to faulty construction and low velocities. The deposits showed evidence of septicity, but were washed out at higher flows. Simpson (165) estimated that the dry solids loading from home garbage grinders is about 0.5 lb. per capita per day and the volume is increased by about 3 g.p.c.d. Trouble may be expected in flat grade sewers, combined sewers, pump wells, and syphons. Additional grit is obtained, requiring better washing. Raw sludge will increase by about 50 per cent, resulting in added loads on digestion and secondary treatment devices. Poole and Erganian (141) reviewed the garbage grinding project at Jasper, Ind. The transformation from garbage cans to garbage grinders in this community has created some sanitary problems, but has had no adverse effect on the sewer system and the sewage plant, which was designed to handle ground garbage as well as sewage.

## Detergents

In a review of the literature on detergents in sewage, Simpson (166) included reports on various operational problems in water and sewage treatment caused by detergents. The increasing usage of detergents suggests the necessity for more research work in this field.

A series of laboratory experiments was conducted by Simpson (167) to show the possible effects of detergents on sewage treatment processes. He found that sedimentation of a clay suspension was greater with the addition of a soap than with equal quantities of detergents. When equivalent sudsing concentrations were employed, the sedimentation efficiency was improved by the detergents exceeding that produced by the soap addition. Greater emulsification of a cooking grease by a nonionic detergent than by soap indicates a lower grease removal in primary treatment and a higher loading in secondary units when such agents are present. The laboratory results also showed that foam production in a fresh domestic sewage is dependent upon the length of aeration and the detergent concentration. The presence of suspended solids reduced foam formation whereas the addition of effluent from an aeration tank seemed to increase the tendency to foam. Simpson observed that Dow-Corning Antifoam A was the most effective defoamer of the samples tried. He believes, however, that the use of such water-insoluble defoamers on a plant scale might not be sound.

Taylor, Bacon, and Suter (176) described several types of surface-active agents with regard to the properties which govern their application as domestic and industrial detergents and the probability and extent of occurrence in sewage and wastes. Information concerning detergent builders and other supporting agents was also presented.

Stericker and Middleton (174) explained various properties of detergents, including wetting, emulsification, deflocculation, and sudsing. These workers concluded, on the basis of a survey of available publications, that considerable disagreement exists as to the effects of small quantities of detergents on water and sewage treatment. Opinion is about equally divided as to whether or not any harmful effect results.

Elton, Hurley, and Waddams (44)

outlined the experience and investigations relating to the influence of synthetic detergents on sewage treatment in the United Kingdom. The reference papers have been reviewed in THIS JOURNAL. The improved procedures for the methylene blue method for detection of sulfated and sulfonated anionic agents in sewage and effluents were also presented.

Sperry (170) has employed a new approach in studying the effect of detergents on sewage treatment by examining the records of the Aurora, Rockford, and Elgin, Ill., plants. A reduction in suspended solids and B.O.D. removals in the primary tank and a decrease in gas production with normal digester operation could be correlated with an increase in detergent usage at Aurora. Data from the Rockford plant exhibited the same general trends. However, the Elgin data were more contradictory and failed to show less gas production. Sperry believes this was due to the lesser use of detergents because of a softened water supply.

## Design and Construction of Plants

Babcock (17) questions certain British practices in sewage works design which the author feels are dictated more by tradition than practical considerations. Brown (28) sees the future developments in sewerage and sewage treatment in the direction of increased efficiency of existing processes and greater emphasis on utilization rather than mere disposal. Hurley (81) points out certain considerations which normally receive insufficient attention in the design of sewage works. These are: effluent quality required, local conditions, legislation, the site, area and levels for the proposed plant, consistency of the effluent quality, ease of operation, maintenance and supervision, the effect of industrial waste, and their pretreatment at the source. A review (7) of the general condition of sewerage and sewage disposal in England showed little or no improvement in 1950, because of shortages of labor, materials, and funds. The status of sewerage and sewage disposal in Sydney, Melbourne, and Adelaide, Australia, is discussed by Barraclough (20). The future of sewage disposal in South Africa is discussed by Hamlin and Wilson (64). Due to shortage of water, effluent filtration to obtain a higher quality of effluent before discharge into watercourses and a greater utilization of effluents is in prospect. A greater use of sludge gas for the manufacture of cyanides, for chemical synthesis, and for carbon dioxide for dry ice is indicated.

Tentative standards for the design of sewer systems and sewage treatment plants were adopted by the Upper Mississippi River and Great Lakes Boards of Public Health Engineers (10).

The basis of design of intercepting sewers and sewage treatment plants of Camden, N. J., was presented by Emerson (45), and for Tampa, Fla., by Langdon (100). The sewage and waste treatment problems in Alaska were discussed by Day (38).

## Hydraulics and Sewage Flow Control

A model study of the hydraulic behavior of storm-water inlets is described by Wen, Geyer, and Benton (196). The theory of this complex flow is discussed and curves are presented to simplify design calculations. Akerlindh (2) presents a method of calculating the amount of storm water that can safely be diverted from combined sewers. Distribution and probability curves and equations are presented which take into account the quantities of sewage, rain water, and stream runoff, as well as stream self-purification capacities.

The British Water Pollution Research Laboratory (195) gives several excellent ingenious methods of controlling water and sewage flow for laboratory and pilot plant experimental work. The equipment described varies from simple vacuum-controlled con-

stant-flow devices to rather complicated intermittent pumps.

### Odors and Sewer Corrosion

A review and assessment of the present knowledge of the mechanics of corrosion of concrete sewers by hydrogen sulfide are given by Parker (132). Pomeroy (140) assembled information regarding experiences with upsewer Cloroben treatment in Southern California. A summary of the observations at eight different locations indicated that Cloroben had no apparent effect and did not eliminate the sulfides. Ludwig and Ludwig (109) studied experimentally the corrosion of cement-bonded concrete sewer pipes by dilute (10 to 20 p.p.m.) and strong (25,000 p.p.m.) sulfuric acid, and a solution of sodium sulfate. In all cases the cement bond of both concrete and cement-asbestos pipe was attacked and deteriorated, which increased with time of exposure but at a decreasing rate. Determination of the amount of chlorine necessary to prevent odors by McLean and Petursson (121) showed that the main sources of odor were the pumping stations receiving wastes from packing plants. It was impossible to obtain consistent values by the orthotolidine method and the amperometric-titration method was substituted. On the basis of these determinations the cost of chlorination to eliminate odors was arrived at.

### Hazards

A serious manhole accident is reported by Raschka and Uber (144). Two men were killed because they entered a manhole deficient in oxygen without proper prior ventilation. The significant point of this disaster is that the sewer had not been put into service and no organic material was present in the sewer. As usual, the first man descended without a safety belt and the second man died trying to save the first. Four others lost their heads and entered the manhole without proper precautions; one a fireman wearing a useless gas mask. Fortunately, sufficient air had entered the manhole so that these men were just able to drag themselves out.

Robinson (146) discusses ventilation of sewage plants and sewer structures. Observations from a hazards survey of some Michigan sewage treatment plants are given and inadequate ventilation designs are shown.

### Rural Sewage Disposal

Studies continue to be made to determine the effect of garbage grinders on septic tanks. McGhan (118) reports that the settling rate of a mixture of garbage and sewage solids will be at least equivalent to and possibly greater than that achieved with sewage solids only. A mixture of garbage and sewage solids, within the ratios anticipated in septic tank influents, will attain about the same rate of digestion as sewage solids only. Adequate initial seeding is important. Preliminary tests on limited soil types indicate that the effluent from a septic tank receiving garbage and sewage may tend to clog absorption fields more rapidly than effluent from sewage alone. When a food waste disposer is used, the septic tank should be increased 50 per cent of the tank capacity (6). A food waste disposer does not add appreciably to the amount of liquid flowing into a septic tank, hence no larger drainage field is required.

Septic tanks having two compartments show slightly better performance in solids retention efficiency than single-compartment tanks of equal liquid capacity (14). A more accurate method of making percolation tests is to use a 4-in. auger hole instead of the 12-in. square dug hole. A bulletin (13) describes planning considerations; house sewer functions; construction, materials, and location of septic tank; absorption fields; and the operation and care of the system. In France it is recommended (1) that rain water should be recovered. Human excreta should be discharged in slit trenches

and kitchen waters stored in a small tank after preliminary filtration. Faulkner (46) reports that for treatment of less than 10,000 g.p.d. a septic tank having a detention time of 24 hr., followed by a filter 6 ft. deep, is generally a suitable scheme for sewage from small rural communities and housing developments. The design capacity of the filter should be about 35 g.p.d. per cu. yd. and, whenever conditions permit, the filter effluent should be discharged over land prior to final discharge. A septic tank (used with a trickling filter) should be designed on the basis of sludge storage and accommodate twice the volume of sludge expected to accumulate between times of desludging. It is preferable to pump tank effluent rather than raw sewage, because smaller, less expensive pumps can be used.

Federick (47) gives a method for estimating the sewage flow from parkway service stations. The rate of sewage flow will equal the rate of flow per fixture and a number of fixtures used simultaneously. Some parts of the disposal system are designed on the quantity of water discharged by each fixture each time it is used, the frequency of use, and the total number of times used a day or during the period of availability.

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## INDUSTRIAL WASTES

### General

Procedures for sampling industrial wastes are described in detail by Black (24). Topics covered included sampling programs, methods of sampling, sampling equipment, flow measuring equipment and procedures, and use of radioactive tracers. Milligan (99) discusses standards for treated industrial wastes, giving reasons for effluent

standards, the relationship of effluent and stream standards, effluent standards adopted by regulatory agencies, and methods of establishing stream standards used by the Pennsylvania State Department of Health. The problems involved in "breaking in" an industrial waste treatment plant are discussed by Orford (116), including treatment plant personnel, waste analyses, operating records, operating procedures, time requirements, and management cooperation. Illustrations of the problems are taken from the first 12 months' operation of a biological treatment plant for gum washing wastes.

Sewage charges have been studied by a joint committee for more than three years (76). The portion of the committee report on industrial waste charges is reported by Schroepfer (132). Topics covered include acceptability of wastes into sewers, present methods of charging, suggested methods for charging, and fair distribution of charges.

Industrial waste control from the viewpoint of the chemical engineer is outlined by Gurnham (64), who discusses waste control from the unit process concept, including oxidation, reduction, neutralization, electrolysis, halogenation, and ion exchange. Miller (98) outlines industrial waste disposal problems in Indiana, where 240 industrial enterprises treat their waste to some degree. Of 163 canneries, 99 have adequate and 30 have inadequate treatment. Accidental spills of toxic solutions are one of the major problems.

### Packinghouse Wastes

Anaerobic digestion of packinghouse wastes on a pilot plant scale (16) has indicated that 24-hr. digestion at 90° F., with contents constantly stirred, resulted in production of 9 to 10 cu. ft. of gas per pound of volatile matter added, reduction of B.O.D. of about 90 per cent, and production of a comparatively odorless sludge. The settling tank discharged suspended solids, unless stirred to cause the solids to sink. Some work remains to perfect the final settling, and costs must be evaluated; but the process appears to be less expensive than aerobic biological processes and an advance in methods of disposing of packinghouse wastes. This work, and many other packinghouse waste treatment plants in the U. S., were visited by Rowntree (127), who reported the anaerobic process to be the most promising treatment process. He initiated pilot plant tests on his return and concludes that high-rate biological filtration would be the preferred type of treatment for New Zealand.

Laboratory tests reported by Fullen (51) show that wastes with a B.O.D. of 1,200 to 2,000 p.p.m. and a pH of 6.6 to 7.2 digest in either the mesophilic or thermophilic range, but control of thermophilic digestion is difficult. With digester liquor as seed, 95 per cent B.O.D. reduction is obtained in 1 to 2 days.

Construction and operation of a small treatment plant for packinghouse wastes was described by Wymore (164). This plant includes primary settling, a low-rate filter operating at a rate of about 2.0 lb. B.O.D. per cu. yd. per day, producing 82 per cent reduction of B.O.D., from 744 to 132 p.p.m. The filter has ponded badly, probably due to overloading or incomplete removal of grease. The plant is quite small, with a flow of about 30 g.p.m.

Composting of paunch manure is described by Rupp (129). The waste is mixed with manure and limestone, piled in heaps and moistened, covered with a 2-in. layer of loam, and stored for three weeks. The temperature reaches 150° F., but drops again after about eight weeks to 100° F. The resulting product is friable, black in color, and has a faint earthy odor. Weed seeds are destroyed and the finished material is used on lawns or gardens. Winter operation was not too successful, but could be practiced inside heated buildings. This procedure

offers a successful way to dispose of manure and paunch manure.

Chlorine and alum are used to treat rendering plant wastes as described by Granstrom (60). Between 120 and 700 p.p.m. of alum and 120 to 240 p.p.m. of chlorine were used. Up to 76 per cent reduction of B.O.D. was accomplished.

Poultry dressing wastes are similar to packinghouse wastes, except for disposal of the feathers. Miller (97) describes a plant handling about 20,000 lb. per day live weight. The wastes are screened through a ¼-in. mesh, held in a septic tank, and then lagooned, with addition of ammonium nitrate. The over-all removal of B.O.D. is 93 per cent, from 385 to 27 p.p.m., although not accomplished in an entirely odorless procedure.

### Fermentation Industries

The treatment of penicillin wastes has been discussed by Muss (108) giving operating results of a pilot plant designed for a flow of 2 g.p.m. and wastes averaging 4,000 p.p.m. B.O.D. High-rate and low-rate filters were operated, the former at 4,800 lb. B.O.D. per acre-ft., followed by the low-rate at 322 lb. per acre-ft., giving over-all reductions from 97 per cent in summer to 80 per cent in winter. Recirculation was 15 to 1. This was considered the best method of treatment.

A full-scale plant for treatment of antibiotics wastes has been described by Brown (28). This plant included aeration for 4.5 hr., to remove solvents, then application to high-rate filters at 5,000 to 7,000 lb. per acre-ft. per day. Recirculation was at about 4 to 1 and B.O.D. reduction fell off from 80 per cent reduction in summer to 50 per cent in winter. Filters have been duplicated as production and flows of wastes increased. The importance of pre-aeration before high-rate filtration was demonstrated.

Penicillin wastes interfered with operation and pre-treatment was necessary, according to Mann (89). Solvents such as formaldehyde and amyl acetate were removed, the latter by aeration. Then the activated sludge plant was able to handle the wastes and produce an acceptable effluent.

The waste penicillin mold has been dried, according to McIntosh (95), and sold at a substantial profit. The dried material is produced at the rate of 100 tons per month.

A high-rate filter operated on a pilot plant scale on distillery wastes is described by Roberts and Hardwick (126). The still residue was evaporated, but about 5 per cent remained to be treated by the biological plant. The high-rate filter handled the wastes at about 2 lb. B.O.D. per cu. yd. (3,200 lb. per acre-ft.), producing about 50 to 70 per cent reduction. Presence of copper was considered undesirable.

Recovery of distillery wastes by evaporation was described by Carson (31). The process recovers 50 tons per day, from a distillery mashing 5,000 bu. of grain.

### Corn and Sugar Processing Wastes

A detailed account of a waste reduction program at a corn products plant is reported by Van Patten and McIntosh (152). A study of each manufacturing process showed that re-use of water and equipment improvement could reduce wastes appreciably. The actual B.O.D. reduction was 92 per cent; product yield was increased 1 per cent without affecting product quality.

Sugar cane processing and sugar refining wastes in Colombia, South America, are described by Stone (140). Efficient sugar plants use less water and lose up to 4 tons less sugar per 100 tons of cane than inefficient mills. Because only 12 tons of sugar can be extracted from 100 tons of cane, great possibilities exist for waste elimination and profit increase by careful process control.

### Chemical and Pharmaceutical Wastes

Wastes from a nylon intermediate plant were disposed of by a variety of

processes, including lagooning, vaporization, pumping down subsurface wells, and sanitary treatment, as described by de Ropp (42). The investment totalled $1,600,000.

Powder plant wastes were treated by Dickerson (43) in a pilot plant including filters, aeration, and final settling tanks. The organic matter, consisting of alcohol, acetone, ether, nitrogen residues, and acids, was oxidized on high-rate filters. Aeration was considered desirable, because of the soluble character of the wastes.

A synthetic rubber plant was described by Dougan and Bell (45). Floating oil was removed by an A.P.I. separator, but there is no further treatment of organic wastes. The large volumes of cooling water reduce the concentration of plant wastes and flow in the St. Clair River disposes of the organic matter by dilution.

Phenol-bearing rubber wastes are treated by coagulation and chlorination, according to Sechrist and Chamberlin (134). Application of chlorine resulted in considerable reduction of color.

Wastes of the Gen. Electric Co. have been surveyed by Watson (156). Cyanides, acids, and metallic wastes are most important, and methods of recovery or destruction are detailed. Jacobs (75) discusses neutralization of acid wastes. Kratz (84) describes experiences with acid waste neutralization in Germany.

The influence of chemical wastes at Niagara Falls, N. Y., on operation of the sewage treatment plant is discussed by Smith (138). In 1950, approximately 85 per cent of the flow to the plant was of industrial origin, including chlorine residues, organic chemicals, solvents, and residues from carbide and ferro-alloy manufacture. Salvage operations at various plants are described.

### Pulp and Paper Wastes

Several aspects of kraft mill effluent improvement were reported in 1951. Allen (2) and Hisey (70) dealt with the removal of sulfides and mercaptans from pulp mill condensates by means of equipment integral to the process. The Bergstrom tower, discussed by the former, is a scrubbing unit in which volatile sulfur compounds are removed from the condensates by stack gas. The latter describes a catalytic process in which the digester and evaporator gases are stripped of sulfur compounds and the sulfur is recovered. Both processes appear capable of reducing potentially toxic sulfur compounds present in kraft mill effluents to an extremely low concentration. A correlation between the 5-day B.O.D. value and the oxygen consumed value of the combined waste water from a kraft mill and a hardwood distillation plant was found by Chesley, White, and Hogg (33). They concluded that the B.O.D. could be calculated from oxygen consumed test results within 80 p.p.m. 95 per cent of the time. The incorporation in original plants of features facilitating effluent control and handling of kraft mill wastes was discussed by Gehm (53). Particular attention is given to segregation of sewers from unit operations so that losses can be readily traced and control measures applied where they will produce the most improvement at the lowest cost. Moggio (104) reported on continuing studies on the biological oxidation and chemical coagulation of kraft mill wastes. Laboratory tests proved that effluents of low strength could be oxidized to a high degree by aeration in the presence of acclimated seed and nutrient salts. Preliminary pilot plant tests of this treatment (111) validated these findings. Lime recarbonation treatment of both combined kraft mill wastes and bleachery wastes was found to be highly effective in removing color and a portion of the B.O.D. However, due to large chemical requirements and sludge characteristics this process must be integrated with the mill recovery system. Results of experiments to this end were also reported.

Summaries and evaluations of proposed methods for handling the sulfite waste liquor problem were published by Gleeson (58) and Barber (19). The former concluded that there will be no single universally applicable solution, because mill size, age, location, and nature of receiving waters vary so widely. The latter suggests shifting to alkaline pulping, for which adequate recovery processes are available and which in most cases would eliminate the pollution problem. Ever-increasing interest in recovery of sulfite waste liquor is evidenced by five papers; Wilcoxson (158) covered magnesium-base recovery, Brunes (29) covered developments in Sweden, La Fond and Holger (85) covered ammonia base, and a plan is described (13) for the evaporation of calcium-base liquor. It appears that many of the difficulties experienced on the first large-scale application of magnesium-base pulping and recovery are being solved. Swedish interest continues in calcium-base recovery because of the fuel problem in that country. Ammonia-base liquor, which lends itself better to evaporation and burning than calcium base, can be substituted for the latter in the pulping process, but the relatively high cost of ammonia and the fact that it is not recoverable are limitations of the process. A unique method employing base exchange for recovering chemicals from sodium-base sulfite waste liquor is described by Bickell and Trethewey (23).

Wiley outlined the research approaches taken to the sulfite problem by Wisconsin mills (159) and with associates (160) also reported on the use of spent sulfite liquor-asphalt emulsions for briquetting coal. Satisfactory evidence was found that good quality coal briquettes can be made with sulfite liquor as the principal binder. On the basis of additional road binder investigations, Sherman (135) predicts a bright outlook for sulfite waste liquor use for this purpose. Field observations reveal that improved methods of application are responsible for the present increased interest in this use. Fermentation research involving sulfite liquor covered ethanol and fodder yeast. Agar and McCarthy (1), comparing ethanol fermentation rates of concentrated liquors, found that calcium- and magnesium-base liquors fermented at about the same rate, whereas calcium dissolving pulp and ammonia-base liquors exhibited a slower rate. Markham *et al.* (90) produced fodder yeast from west coast sulfite liquor which was similar in all characteristics to that produced in Wisconsin and in Europe. Operation of the one large-scale fodder yeast plant operating in this country was described by McGinn (94).

Progress in semi-chemical pulping waste treatment and its treatment in combination with sanitary sewage were discussed by Opferkuch (117)(118)(110). Anaerobic digestion at loadings as high as 0.1 lb. per cubic foot of digester capacity were obtained on nutrient salt supplemented waste at B.O.D. reductions of between 50 and 75 per cent. Neutral sulfite can be treated in conjunction with sanitary sewage if adequate capacity is provided. In the case of primary treatment, the dissolved B.O.D. contributed by the waste has an additive effect on the effluent in proportion to the percentage present in the sewage. Of interest from the standpoint of subsequent control, treatment, or recovery of semi-chemical wastes, is the work of Keller and McGovern (79), in which spent cooking liquor was recycled in the pulping process, yielding higher solids concentration prior to rejection.

In outlining the status of strawboard waste handling, Bloodgood (26) traced the raw material losses through the process and cataloged the significance of each from the solids and oxygen demand standpoint. Progress in the attempt to apply anaerobic digestion to treatment of the waste was traced and future research suggested. Jung (78) reported similar anaerobic digestion studies. Controlled lagooning

at a strawboard mill at Noblesville, Ind., was described by Krancher (83). Solids removal, oxidation, and metered discharge are all accomplished by the system described.

The limited literature on the nature and volume of wastes produced from pulping rags, rope, and jute was substantially supplemented (109). Flows, solids, oxygen demand, alkalinity, and other characteristics of the wastes produced by each stage in the pulping of these materials were presented, together with some analyses of the organic constituents.

Methods for treating de-inking mill waste by physical, chemical, and biological methods were outlined by Palladino (119) and performance figures based on pilot and full-scale operations were presented. The same author (121) described a demonstration plant erected to determine the effectiveness and cost of biological oxidation of this waste. Primary treatment results at several plants handling de-inking waste were presented by Palladino and Baigas (120). These data showed that substantially all the settleable solids and more than 50 per cent of the total suspended solids were removed and that the sludge could be vacuum filtered at reasonable filter loadings. Sedimentation of mixed pulp mill wastes containing de-inking effluent and dewatering of the resulting sludge was studied by Erspamer and Rice (49); 86 per cent of the suspended solids were removed by 2-hr. settling, but B.O.D. reduction averaged about 15 per cent. Dewatering on a vacuum filter gave loadings of only about 2 lb. per sq. ft. per hr.

Bass and Evans (22) and Gehm (54) published summaries of mill practice in treatment of white waters by various clarification methods. Results obtained by chemical coagulation and sedimentation were detailed by Knack (82). Excellent clarification was obtained at high alum dosages and it was possible to use the clarifier underflow back in the process, thus recovering the fiber content. Fundamental research by Amberg (3) on the oxidation of board mill effluent concentrated in strength by repeated recycling was of considerable interest. Shallow storage at favorable temperatures in the laboratory after supplementation with nutrient salts and seed liquor produced high B.O.D. reductions in relatively short periods. The effects of fiber loss from paper mills on streams and connected sewage treatment systems were reviewed by Nemerow (112).

Observation of color reduction in streams containing pulping wastes were recorded by Churchill (34). Research on pulp and paper mill wastes at the Lawrence Experiment Station was summarized by McCarthy (93). Snow (139), in describing industrial waste treatment in Connecticut, included paper mills in his review.

### Cannery Wastes

Pertinent information relative to the types of treatment and scope of the problems involved in cannery wastes (and other industrial wastes) in Indiana (98), Illinois (148), Minnesota (151), and Wisconsin (161) was presented by representatives of the state health departments and pollution control agencies.

Drake and Bieri (47) discuss the disposal of effluents from pea and corn canning plants in Minnesota by ridge and furrow irrigation and by the relatively new spray irrigation method. With either system more land is required for disposal than by lagooning. Properly operated irrigation systems should not develop offensive odors, hence do not require the expensive odor control measures associated with many lagoons. The initial cost of an irrigation system may be considerably less than the initial cost of a lagoon. Ground-water contamination is listed among the possible disadvantages of irrigation.

Dougherty (46) presents data on the treatment of cannery wastes, principally tomato and peach wastes, in a full-scale chemical treatment plant.

The average B.O.D. reduction was 47 per cent. Experimental data for the anaerobic digestion of wastes at 97° F. show reductions in B.O.D. of 75, 72, and 51 per cent with apple, tomato, and peach wastes, respectively, during 7-day detentions. The quality of the effluents from anaerobic digestion was not considered to meet requirements because of the strong odor, black color, and inability to reduce the B.O.D. below 200 to 250 p.p.m. Laboratory experience with an accelerated activated sludge treatment suggested that this method of treatment was capable of effecting greater efficiencies at a lower cost over present conventional methods.

In a brief review of some applications of an integrated flocculation and sedimentation unit for the treatment of industrial wastes, the results obtained with green and dry bean wastes are given (22). Green bean wastes with an average B.O.D. of 398 p.p.m. were reduced by 54 per cent over a one-month operation. A spot check during navy bean processing gave a B.O.D. reduction of 55 per cent when the influent B.O.D. was 2,780 p.p.m. Templeton (143) briefly discusses the several methods of cannery waste treatment in use at the plants of Stokely Foods, Inc., and also discusses in considerable detail the work of the National Canners Association on the anaerobic digestion of pea and corn wastes. Sanborn (130) describes methods for odor control and disposal of pea stack juice. Marsh (92) presents a brief description of the third year of operation of a pilot plant installation for the conversion of pear wastes to pulp and molasses feeds. Treatment on a continuous basis was made possible by redesigning certain equipment, particularly for the preparation and dejuicing of lime-treated pear pulp. Stock feeding tests of both pulp and molasses show that they are satisfactory for animal feeds.

The presence of small quantities of essential oil normally present in citrus wastes was found to exert an inhibitory effect on the methane digestion of this waste (96). Yeast fermentation with aeration was found to be a suitable means of removing the inhibitory oil. The disposal of 700,000 gal. of citrus by-product wastes containing 6 tons of B.O.D. per day was accomplished by spreading the untreated wastes onto porous sandy soil basins under conditions conducive to uniform spreading (88). Absorption areas are used alternately for waste disposal and the growing of crops.

Wright (163) presents a brief but instructive review of the steps taken over a period of years at a citrus juice plant to reduce wastes losses by conversion to animal feed, molasses, and oil. Aeration of the unrecovered waste waters with *Torula utilis* is employed to reduce the concentration of fermentable solids prior to discharge into a bay. Propellers installed in the bay end of the discharge pipe provide improved dispersal of the wastes. The same author (162) discusses the extraction of oil from citrus seeds, a waste product from the processing of citrus juices. Vincent (153) reviews the development of by-product feed and molasses from citrus canning operations.

### Dairy Wastes

Stimulated by the increasing cost of milk and the increasing cost of waste disposal, the interest in dairy waste saving and waste utilization is definitely increasing.

Dean (41), as chairman of the Task Committee on Waste Disposal of the Dairy Industry Committee, reported on the continuing efforts of this energetic group towards better dissemination of waste-saving information and towards more research in the field of dairy waste treatment. Eldridge (48) reiterated a list of 15 excellent waste-saving recommendations issued by others in previous years. Waste prevention efforts at the Belle Center (Ohio) Creamery reduced the pollu-

tion load 70 per cent, from a population equivalent of 3,000 to 900.

Schwarzkopf (133) reported on milk losses connected with the dumping of 10-gal. milk cans brought from the farms. It was found that by correct dumping and by allowing a 24-sec. draining time, the milk wasted to the sewer from the cans during the milk dumping and can washing operations can be kept to less than 0.1 per cent of the total milk handled. This corresponds to a waste load of less than 1.2 lb. B.O.D. per 10,000 lb. of milk handled, which is an important reduction from what was considered good practice some years ago. This waste load can be still further reduced by using a small "volumetric" prerinse that is collected with the drip milk, but this makes the drip milk more difficult to dispose of, even for animal feed.

Carrick (30) discussed the great value of whey products for poultry feed. Murdock (106) reviewed progress in dairy by-products utilization, largely based on the information contained in the new book by Whittier and Webb (157) on "By-Products From Milk," which in itself should be a valuable aid in the elimination of pollution due to dairy waste.

Wisniewski and Muegge (161), in reporting on the 2,250 dairy plants in Wisconsin with their 15,000,000,000-lb. annual milk volume and estimated losses of 2 per cent, stressed the importance of good housekeeping in preventing stream pollution due to dairy waste. They state that 60 per cent of the cheese whey in Wisconsin now goes to condenseries; the remainder, 3,000,000,000 lb. annually, is returned to the farmers for direct feeding.

Uber and Rogers (151) reported from Minnesota that a majority of the 800 milk processing plants in the state discharge their waste to municipal systems. Trickling filters are widely used.

Troemper (148), reporting on conditions in Illinois, stressed the importance of reducing treatment costs by waste saving and simplified waste disposal plant design. He feels that a modified activated sludge type of treatment gives low-cost treatment with a reasonably satisfactory effluent.

Rugaber (128) reported on various difficulties experienced since 1937 with the trickling filter at a large milk evaporating plant at Coldwater, Ohio. A 1939 report by the Ohio State Department of Health showed very good results, but since then the operation had deteriorated for various reasons. The author found it necessary in 1946 to clean out the whole plant, including the underdrains and the slag in the filter. He also increased the recirculating rate to 5:1, installed aeration in the flow equalization tank, and changed the system of sludge handling on the drying beds. The author concludes that a trickling filter plant properly designed and properly operated can do an excellent job of milk waste treatment, but that its cost is excessive and that it is definitely not an economical answer to the dairy waste disposal problem.

In general, there is an increasing interest in the use of activated sludge type of treatments for dairy waste, and Hasfurther (65) again reported on the aerated return sludge type of treatment plant at Huntley, Ill., which he reported on in 1950 when it supposedly had less satisfactory means of air diffusion. The published data indicate erratic performance. The author stated that no regular facilities for disposing of excess sludge are needed. This is interesting, because in the light of experience elsewhere, it would appear that this plant has insufficient air and insufficient aeration tank depth and volume in proportion to the B.O.D. loading for complete disposal of excess sludge by aeration.

Thayer (145) reported in some detail on two different waste treatment plants in Ohio (Schell Creamery and Blossom Hill Dairy) of the same general type as above. For both of these plants, it is also claimed there is no excess sludge which has to be treated anaerobically

or otherwise disposed of outside the disposal plants. However, these two plants operate with relatively much more air (2.4 and 4.0 c.f.m. per pound of B.O.D. per day) and aeration tank volume (1.5-day retention) than the Huntley plant previously mentioned.

Thayer, in another paper (144), again described briefly the two plants discussed in the first paper and also gave brief descriptions of three other plants in Ohio of a similar type, two of which have been in operation for many years and have been described previously by others (New Bremen and Belle Center) and a fifth one (Cherry Grove) that is new. All of these plants appear to have a very generous air supply and aeration tank volume. It might be noted that it has always been reported that both the New Bremen and the Belle Center plants have had to remove a certain amount of excess sludge from the aeration system.

Thayer stressed that the operation of the three new plants is extremely simple and that the ratio of sludge return is not critical (presumably above a certain point). He feels that there is a great advantage in having an aerated holding tank ahead of the regular aeration tank which is inoculated with return sludge. Actually, no proof is given that better or just as good results would not be produced with the same amount of air and the same total tank capacity if both tanks were used as aeration tanks with variable level in order to equalize the flow through the settling tank. This latter method of operation might be preferred where a plant is operated with one blower so that the head pressures over all diffusers would remain the same. Also, it may provide for better utilization of the total air supply.

Hoover and associates (72) of the Eastern Regional Research Laboratory have continued their laboratory aeration studies of milk waste. They have previously suggested aerobic fermentation (or activated sludge treatment) followed by centrifuging instead of coagulation and settling. They now suggest a fill-and-draw activated sludge process similar to what has been tried from time to time by others.

In regard to commercial use of centrifugation as a step in dairy waste disposal, it will probably be found that centrifuges are too costly to buy and operate. As regards a fill-and-draw activated sludge system, it might well be found that the sludge is apt to go septic during the drawing period.

In another paper by the same authors (74), they go into more detail about the rate and extent of oxidation of skim milk, casein, and lactose by activated sludge as determined by manometric and chemical analyses. The value of the work of these authors is in the wealth of data they have published that help explain the biological reactions taking place in the aerobic treatment of dairy wastes, and which in the long run are bound to help simplify and lower the cost of dairy waste disposal.

As an interesting by-product to this work on dairy waste, the Eastern Regional Research Laboratory group (123) (73) has become interested in the various possibilities of obtaining yeast and other valuable feed supplements from dairy by-products and from activated sludge produced from either dairy waste or city waste. Both types of waste produce activated sludge rich in at least certain kinds of vitamin $B_{12}$, which, however, may or may not be of the type that is of greatest benefit in animal feed.

### Tannery Wastes

Thorstensen (146) makes the statement that tanneries must invest in waste treatment facilities if they are to continue in operation. He reviews the problems that the industry must face and outlines possible solutions. Reuning, Harnly, Benrud, Morris, and Marshall (4) presented papers on the treatment and recovery of chrome wastes, conservation of chrome, treatment of vegetable tanning wastes, and

the methods used in the disposal of wastes at a tannery in Bolivar, Tenn. To handle a chrome tannery waste containing 1,175 p.p.m. of suspended matter the construction of a sewage farm to prevent the discharge of the tannic and chromic acids to the stream was considered, as well as the construction of a pipeline to the sea (8).

### Textile Wastes

Helmers and Sawyer (69) reported on the nutritional requirements of activated sludge when used in the treatment of cotton kiering waste. Mixtures of domestic sewage and the waste give indications of a possible treatment method. The studies show the maximum and critical nitrogen requirements of the organisms. There is no reason to believe that there is a shortage of phosphorus in the mixtures of sewage and waste. One of the South's largest synthetic fiber plants (17) treats sanitary sewage, sulfide, alkali, and acid wastes by mixing, thereby using the alkaline wastes to neutralize the ones that are acid. Additional neutralization is accomplished by automatic pH control. Hazeldine (68) states that waste bleaches normally require caustic soda recovery plants, as do mercerizers. Some waste bleaches need de-greasing plants. Starch should not be discharged, but should be caught under the starch mangles and trucked to a dump; indigo dyes should have indigo recovery tanks. The waste bleaches require screens for the recovery of fiber. Klein (81) gives the general methods for treating textile wastes by physical and chemical means; for neutralization he discusses the use of sulfuric acid and lime, for color removal bleaching powder or sodium hypochlorite, and for coagulation he mentions the use of sulfuric acid, lime, alum, ferrous sulfate, and copperas. The mercerizing wastes are treated by evaporation with the recovery of caustic soda. Kier liquors are made acid to methyl orange with sulfuric acid, which precipitates some of the organic matter and removes some color. Cotton dyeing wastes are said to be treated with bleaching powder, hypochlorite, or bleach liquor to destroy the sulfide. Another method is to precipitate with copperas and lime. This is said to remove the sulfide as iron sulfide; aeration is used to assist in the flocculation. In rayon manufacturing the waste caustic liquors can be dialyzed to remove dissolved hemicelluloses and thereby make it possible to recover the caustic soda for re-use. The waste acid liquors can be filtered, evaporated in an acid regeneration plant, and crystallized to remove $Na_2SO_4$ and other salts, and recover most of the sulfuric acid. A new process for the treatment of sulfide liquors containing sodium sulfide and polysulfide has been tried, consisting of aeration of the liquor in a tank partially filled with stone. A sulfur bacteria developed on the stones converts the sulfide to sulfate and thiosulfate.

The New England Interstate Water Pollution Control Commission has published an extensive review on textile wastes (113).

Goode (59) describes a waste treatment plant that handles wool fulling, scouring, and finishing wastes at a daily cost of about $30 for a flow up to 1 m.g.d. The process used is rotary screening, chemical flocculation, chlorination, and sludge lagooning. The B.O.D. is reduced from 280 to 20 p.p.m.

### Petroleum Processing

At the Humble refinery (14), responsibility for waste treatment is divided between the Process and Oil Movement Divisions. The laboratory arranges and conducts waste-water surveys. A Committee on Waste Disposal is responsible for long-range planning. Rae (124) described the waste disposal system at Sarnia, Ont., in detail, including refining wastes, subsurface injection of brines, removal of waste solids, and phenol control.

Development of zoogleal bacteria in oil-water separators and sewers has

complicated the problem of oil separation because the gelatinous material absorbs a relatively large amount of oil. Redlien and McClintock (125) found that hypochlorite provided the best control; an 0.1-p.p.m. chlorine residual destroyed the growths in 15 min. Copper sulfate up to 2.5 p.p.m. apparently accelerated the growth, and 10 p.p.m. was not completely effective. The authors note that alkaline wastes should not be discharged to sea water, because the precipitated magnesium hydroxide absorbs oil. Oil-bearing solids have either been incinerated or washed with hot water plus aeration to recover oil.

Giles (55) pointed out that highly effective operation of A.P.I. gravity separators can be attained only with "clean" oil-water suspensions because complex mixtures of oil, emulsions, and settleable solids retard separation. Even with efficient operation, this equipment will not effect quantitative separation of oil, and it should be regarded only as a primary treatment. He cited the improved separator operation that resulted when boiler-water treatment sludge, residual water from emulsion treatments, and materials promoting emulsification were excluded from the separator influent. Giles *et al.* (56) discussed the function and design of gravity separators, concluding that a substantial portion of the oil in separator effluents can be attributed to inherent design features and that the remaining portion, because of non-separability, cannot be removed by a separator of practical size. In a prepared discussion, Rohlich reported on a laboratory study of basic separator design features, indicating the desirability of submerged wastewater inlets to overcome disturbance of hydraulic behavior caused by the nappe velocity of an influent weir.

A small-scale Accelator following an A.P.I. gravity separator was operated by Austin and Vause (18). They found dolomitic lime better for pH control than caustic soda, soda ash, or water-softener sludge. Using alum as coagulant, best results were obtained at pH 8.5; ferrous sulfate gave best results at pH 9, but a satisfactory effluent could be obtained over the range 8 to 10. This wider flocculation range was a distinct advantage, because of large pH fluctuations of the influent water. Oil was reduced 91 per cent, turbidity 93 per cent, and B.O.D. 50 per cent with 25 p.p.m. $FeSO_4$, 10 p.p.m. activated silica, and 150 p.p.m. dolomitic lime. Barry (20) reported that two A.P.I. separators in series failed to remove enough oil to meet requirements. A Gibbs diffusion unit was installed in a storage tank feeding the separators. Without chemical treatment, oil was separated from the clay particles and could later be separated from the water in the A.P.I. units. D'Arcy (39) stated that properly designed and operated dissolved-air clarification has been effective in removing free oil from waste water. When colloid-forming chemicals are added, flotation will often produce effluents containing less than 25 p.p.m. free and emulsified oil, less than 100 p.p.m. suspended solids, and the B.O.D. and the $H_2S$-generating capacity will be reduced substantially.

Treatment of waste water from white oil manufacture was described by Schindler (131). Exhaustive treatment of suitable petroleum fractions with fuming $H_2SO_4$ is required to produce technical and medical white oils. The acid sludge is disposed of by burning; the $SO_2$ evolved is converted to fresh acid in a contact plant. Cooling of the gas by direct water contact produces a waste containing $SO_2$ equivalent to 0.1 to 0.2 per cent $H_2SO_4$, the largest component of the refinery waste. The other waste is highly colored, acid or alkaline, contains water-soluble sulfonic acids, and sometimes emulsified oil. This process water is adjusted to pH 5 with waste water from the acid plant. Sulfonic and mineral acids are then neutralized with hydrated lime to pH 7 to 8.4 in a

plant providing continuous settling and supernatant discharge. This plant treats 18,000 to 40,000 g.p.d. Color is reduced from 1,700 to 5,100 to 30 to 60 p.p.m., and oxygen consumed from 460 to 760 to 35 to 50 p.p.m.

Employing extraction and distillation techniques in proper combination, it should be possible to recover compounds suitable for varnishes, drying oils, solvents, detergents, resins, insecticides, catalysts, etc. (5). Bartholomew (21) claimed that spent acid from alkylation plants, which contains 88 to 92 per cent $H_2SO_4$ and 6 to 10 per cent hydrocarbons, could be used to produce fresh acid by spraying it into a furnace for decomposition at 2,200° F. Heat would be furnished by the hydrocarbons in the waste, plus additional gaseous fuel where necessary, the hot gases passed through a recuperator to preheat the furnace air, scrubbed with acid, cooled by direct water contact, the $SO_2$ recovered by air-stripping, dried by scrubbing with concentrated $H_2SO_4$, and passed to a contact plant. Bland reported (25) that 12 oil companies have released previously restricted information on re-use and regeneration of spent alkylation acid. Although practice differs considerably, this waste product was found to be satisfactory for treating naphthas and furnace oils. Lube stocks can be processed with it, provided a subsequent re-run step is used and somewhat lower filter yields can be tolerated. Waxes have been refined with spent acids, but results have not been uniformly satisfactory. Slade (137) has written a general discussion of waste recovery and prevention of sludge losses in treating petroleum distillates with $H_2SO_4$.

Wastes from organic chemicals manufactured from petroleum hydrocarbons are reported from results of a research project by the Southwest Research Institute (11). Dichromate used for corrosion control interfered with D.O., B.O.D., $Cl_2$, and formaldehyde tests, and improved methods were developed to reduce interferences; however, no details are given. Tables are given for B.O.D. recovery by the new method. It was also found that the minimum toxic amount of dichromate was 70 p.p.m. for goldfish and 200 p.p.m. for bluegills. Because the plant is in Texas, solar evaporation from spray ponds is feasible. Evaporation is aided by pumping pond water to spray nozzles at the top of tall pipes.

Fellows (50) discussed recharging oil-well brines, separation of oils and tars, and disposal of alkali wastes at refineries.

## Coal Wastes

Suggestive findings on acid mine water were announced by Temple and Colmer (142). Acid water forms in active, inactive, or abandoned coal mines, or in gob piles, but never in seams not opened by mining. The pH of such water may be as low as 2, and there may be titratable acidity of several thousand p.p.m. Ferrous sulfate is the predominant dissolved salt, but sulfates of calcium, magnesium, and aluminum are also usually present. The metal and sulfate ions balance, indicating the absence of free acid. Ferrous iron is not oxidized by air if the pH is low, and the authors claim discovery of a specific bacterium, as yet unclassified but not remotely resembling known iron bacteria, that causes oxidation under this condition. When acid water was treated with a bacteriacide or passed through a Seitz filter, there was no oxidation. When such water was seeded with untreated mine water, oxidation occurred. The authors also claim that *Thiobacillus thiooxidans* is an important factor in mine acid formation. Other investigators maintain that mine acid formation is purely a chemical reaction, and that the presence of *T. thiooxidans* is merely adventitious.

Coal washery wastes often cause critical problems on small streams where they are the only source of pol-

lution; Gillenwater (57) states that although coal operators are urged to cooperate, a definite program is impossible without a legal foundation. The effect of silt on streams is mostly physical, but the cost of purifying water from silt-laden streams is rising steadily. Ponds of adequate size provide a simple and efficient desilting measure. Pumpage of the waste water to abandoned mine sections is sometimes practiced, and some operators use clarifiers and filters.

Siebert (136) presented an historical review of the anthracite industry and surveyed wet-preparation practice. At peak season production the hard coal area of Pennsylvania may have discharged 1,800,000 tons of silt annually to the Schuylkill River, recently dredged in the largest operation of the kind ever undertaken. Silt settling basins are widely used; a 3-hr. detention period reduces suspended solids to less than 1,000 p.p.m. When Pennsylvania initiated clean-up measures 19,000 tons of silt were being discharged per day; this has now been reduced to 2,000.

Fish killings following intense local rains during low stream stages were traced to acidic water flowing from a coal mine gob pile. Gross and Lee (62) stated that the problem was solved by impoundment of the drainage by a levee on the stream bank.

### By-Product Coke Wastes

A comprehensive paper on treatment and disposal of coke plant wastes by Marsden (91) describes the various wastes and the treatment methods that have been used. A number of tables list representative compositions of the liquors and state their effects. Legal aspects, methods of charging for municipal disposal, effluent standards, and toxicity are discussed.

British legislation affecting coke works was reviewed by Bondy and Priestley (27), who then described several treatment plants briefly and the new Bolsover plant in detail. Low-temperature carbonization of coal produces 1,200 g.p.h. of phenolic liquor with 30,000 p.p.m. O. C.; 1.5 per cent phenol [by bromide-bromate; 0.2 per cent proved to be $(NH_4)_2S_2O_3$]; 0.13 per cent free $NH_3$; 0.44 per cent total $NH_3$; 0.07 per cent total S; and 8.5 to 8.9 pH. It was decided to improve this liquor to the maximum practical extent and help pay the cost with by-product recovery; the aim was 90 to 95 per cent efficiency. Analysis disclosed that the phenolics were 65 per cent mono- and 35 per cent dihydric. Trial extractions showed that benzene, toluene, butyl chloride, and aliphatic hydrocarbons were ineffective. Ether was very good, but too dangerous for plant use; butyl acetate proved to be satisfactory; methyl isobutyl ketone was an even better solvent for the dihydrics, but it was more soluble in water (2 *vs.* 0.8 per cent) and required more stripping steam for recovery. Trials indicated that a packed tower, using a liquor/solvent ratio of 8:1 (much lower than for benzene), would yield the desired results. The liquor is quite corrosive to mild steel and cast iron, but not to aluminum; care must be taken to guard against electro-corrosion between aluminum and steel at elevated temperatures. On the basis of the experimental work the commercial plant was designed, yielding a stripped liquor with a phenol content of 0.07 to 0.1 per cent and an oxygen consumed value of 270 to 300 p.p.m.

Phenol removal and complete purification of waste water from coal carbonization were discussed by Crotogino (38). Waste disposal and recovery problems are particularly severe in lignite hydrogenation; wastes from the various steps must be treated separately because of differences in composition. Oil separation, phenol extraction, $NH_3$ recovery, and $H_2S$ removal are described. Final purification of the combined effluents after pretreatment is difficult because

of the high phenol content. Biological purification, combined with activated carbon treatment, gave satisfactory results at reasonable cost. Addition of asbestos resulted in increased capacity and stabilized operation of the biological unit.

A preliminary report on the cooperative study of chemical oxidation of dephenolized ammonia liquor, was given by Cleary and Kinney (35). The full report, published by the Ohio River Valley Water Sanitation Commission (115), states that phenols can be completely oxidized by chlorine, ozone, or chlorine dioxide. Also, O.C. and B.O.D. values were materially reduced by each oxidant. A relatively small dose of oxidant reduced the phenol content of the liquor substantially, but increasingly heavier doses were required to lower the phenol further. The results of this investigation indicate that: (a) phenol content of the liquor is not the sole basis for determining the oxidant dose; (b) there was no correlation between the O.C. values and oxidant demands; (c) no temperature adjustment was necessary except for chlorine, which tends to form chlorates above 45° C.; (d) a pH of 7 to 10 was best for chlorine oxidation; (e) with chlorine, the ammonia had to be completely oxidized before the phenol breakpoint could be reached; (f) complete oxidation was essential to avoid the presence of chlorophenols; (g) chloride content increased in proportion to the amount of chlorine used, chlorine dioxide increased it slightly (1.5 per cent), whereas ozone had no effect; and (h) chlorine and chlorine dioxide in series showed no advantage, but a mixture of the two reduced the net dosage substantially. Important as this study was, further research will be required before the problem can be solved. Murdock (107) discussed the data on chlorine and chlorine dioxide, and gave additional data for refinery wastes containing sulfides. He calculated the cost of ozone oxidation (using commercial oxygen) of still waste for a 100-oven plant at 3¢ per ton of coal coked. For a 300-oven plant the cost would be 2¢, and with low-cost oxygen this figure could be reduced to 1.25¢. The life of an ozonator is estimated to be 24 yr., but a 12-yr. write-off was used in the calculations.

A new method for destroying residual toxic substances in ammonia still liquor was proposed by Cooper and Bouch (36). Their experimental work indicates that nitric and nitrous acids are practicable for the purpose. Nitric acid decomposes inorganic salts, such as thiocyanates and thiosulfates, and the gaseous products, after oxidation by air, can be recovered for reuse. The total effect is to convert toxic salts to harmless compounds by using atmospheric oxygen indirectly. Phenolics, however, combine with nitric acid, which then becomes irrecoverable. Nitrous acid, if an excess is used, works as well as nitric in the proposed process.

### Pickling and Acid Wastes

A number of proposals for using spent pickle liquor were advanced by Jones (77). He suggested making zinc chloride and zinc sulfate from pickle liquor and sal skimmings, with pigment-grade iron oxide as a by-product (cf. Ref. 221 in 1949 Review); treating brass and copper scrap to make zinc and copper sulfates; recovering manganous sulfate by extraction of low-grade ore (cf. Ref. 650 in 1950 Review), and treating the solution with aluminum metal to produce manganese or ferro-manganese; using aluminum shavings to precipitate iron powder and recover aluminum sulfate; adding ammonium sulfate to produce ferrous ammonium sulfate; converting phosphate rock to superphosphate; and using caustic soda to make sodium sulfate and iron oxide. Some of these proposals have been tried and found wanting, others would require considerable basic research. Ferrous am-

monium sulfate would be a desirable product if it could be made cheaply enough; it is a stable salt, valuable as a fertilizer component for its iron and nitrogen content, which overcomes chlorosis in plants and trees.

Operation of the string-discharge vacuum filter for filtering lime-neutralized pickle liquor sludge was described by Guillot (63). His data were drawn largely from the pickle liquor neutralization pilot plant operated by the Marblehead Lime Co., which showed that such sludges could be handled practically on a rotary vacuum filter (cf. Ref. 302 in 1950 Review). A nomograph for determining the weight of lime required for complete neutralization of pickle liquor was published by Hoak (71).

Information on the various types of limes and limestones, and their comparative costs for a theoretical plant located in New Jersey, was prepared by Jacobs (75). High-calcium limestone of ½- to 1½-in. size in beds 5 to 6 ft. deep will provide effective neutralization for HCl and $HNO_3$ in 5 per cent strength at a rate of 5 g.p.m. per sq. ft. Neutralization of $H_2SO_4$ in such a bed is ineffective at an acid strength greater than 0.3 per cent; the flow rate at this concentration must not exceed 1 g.p.m. per sq. ft. Dolomitic stone has 15 to 16 per cent greater neutralizing value than high-calcium stone, but the flow rate must be much lower because of the slower reaction rate. Limestone ground to 20-mesh will neutralize $H_2SO_4$ in 45 to 60 min., but this time can be cut to 30 min. by using a 10 per cent excess. A special type of limestone, containing a trace of graphite, is found in New Jersey; it is highly reactive. A plant is described (10) in which an acid waste, plus a small amount of alkaline waste, flows at 65 g.p.m. to a 4,500-gal. equalizing tank. The mixed waste flows to a 200-gal. chemical treatment tank for addition of lime slurry, from whence it overflows to two 4,500-gal. tanks, in series, with slow-mix paddles; and from there to a final settling tank. The pH of the plant waste varies from 1 to 6, the final effluent from 7 to 10; it contains a maximum of 1 per cent total solids. Lime slurry is fed automatically by a pH controller actuating two feed lines (½- and 1-in.) to attain close control.

Several waste treatment plants in Connecticut were described by Snow (139). A pickle liquor rinse-water neutralization plant is practically identical to reference (10) above. A plating waste contains chromium, nickel, and cadmium. After adjusting the pH to 2 to 3 with $H_2SO_4$ it is treated with metabisulfite, the pH is increased to 7.5 with lime, the waste is settled, the supernatant is discharged to a sewer, and the sludge is hauled to a lagoon. A cyanide waste is treated by circulating it through the ejector of a chlorinator, with caustic soda added for pH adjustment. The waste is discharged to mixing and settling tanks; after a 2-hr. detention period the supernatant is decanted if the pH is 8.5 and it contains 2 p.p.m. chlorine residual.

Successful treatment of waste water from an axle manufacturing plant by lagooning was described by Griffith (61). The waste water, containing acid and alkaline cleaners, mineral and emulsified oils, solvent emulsions, paint, boiler compounds, and coal pile drainage, flows to a small and a large subsidence basin in series. Oil skimmed from the small basin recovers part of the treatment cost. The large basin provides 25-day storage. This procedure reduces the B.O.D. by 93.4 per cent, suspended solids by 83.1 per cent and oil by 95.2 per cent; it is a low-cost, high-efficiency disposal method that meets the requirements of the local department of health.

### Plating and Cyanide Wastes

The chemistry of cyanide treatment was reviewed by Milne (102). Where cyanide waste is neutralized by dilution with stream water, the bicarbonates present tend to buffer the mixture at pH 7. Under these conditions NaCN

is hydrolyzed to HCN and NaOH; the latter combines with atmospheric $CO_2$ and maintains the buffering capacity. Another possibility in neutralization is hydrolysis of HCN to ammonium formate and azulmic acid; calcium and magnesium ions are reported to promote this reaction. Cyanide ions form tight complexes with certain metals, some of which dissociate very slightly, and precipitation of ferrous ferrocyanide has been used as a treatment method; but an excess of hydroxyl ions reverses the reaction and the precipitate is difficult to handle. Treatment with a nickel salt has been proposed, because the nickel complex continues to form as long as nickel ions are present. Precipitation of cyanide with spent metal salt solutions has been proposed to recover the metal, but it is difficult to control the concentration of heavy metals whose ions may be toxic. The most popular cyanide disposal method is alkaline chlorination, but cyanide complexes complicate the reaction and more research is indicated. Alkaline permanganate has been proposed, but the reaction is uncertain and the sludge is hard to handle. Thiosulfate oxidizes cyanide to thiocyanate, but this ion is slightly toxic. Alkaline chromate oxidation of cyanide to cyanate has been suggested, but the reaction is quite slow; if a catalyst could be found, this would be a boon to chromium platers. The copper-ammonia complex converts cyanide to cyanate and precipitates cuprous cyanide, but reaction conditions have not been established. Lime-sulfur has been used to convert cyanide to thiocyanate, but this is not a reliable treatment because the product is toxic. Cyanide reacts with bisulfite addition products of aldehydes and ketones to form hydroxynitrile or cyanhydrin, which either precipitate or hydrolyze to ammonia and various hydroxy compounds; these reactions are generally only of academic interest.

Lack of knowledge of limiting concentrations of plating waste in streams was cited by Langford (87), who briefly discusses neutralization, with pH control; alkaline chlorination; acidification with removal of HCN by aeration; copperas and lime treatment; and copperas reduction of chromates followed by lime precipitation. The Prussian-blue test for cyanide is deemed adequate where treated waste is discharged to sewers, but the benzidine hydrochloride test is recommended for low concentrations. One district in England (9) established the following limits, in p.p.m.: CN, 1 to 3; Cr, 6 to 8; Fe, 12 to 16; suspended solids, 20; and pH, 6 to 9.

At one plating plant (80), acid and alkaline waters are scheduled for discharge at the same time to effect partial neutralization in the sewer. The waste then flows to six 3,000-gal. tanks, of which the first four are baffled and the last two have agitators. Caustic is fed to the last tank as a 20 per cent solution by automatic pH control; one valve feeds 0 to 2 g.p.m., the other 0 to 30 g.p.m. Dilute cyanide waste flows to two 6,000-gal. tanks, with agitators, to provide 1-hr. detention and equalization. Automatic chlorinators operate when waste flows from these tanks, and caustic is added to maintain pH 8.5, to form cyanate. Concentrated cyanide (15,000 p.p.m.) is completely treated by batch alkaline chlorination. Data on chlorine and caustic soda are given. At another plant (7) cyanide waste is produced intermittently. It flows to a storage tank, from which it is pumped proportionally to main plant waste flow of 125,000 g.p.d., thus yielding a constant, low concentration. Caustic is added by automatic pH control, and the cyanide is oxidized by chlorine. The waste flows to a holding tank where more caustic and chlorine are added to maintain a residual of 1 to 3 p.p.m. in the clear effluent.

Dodge and Zabban (44) report on studies of various stages of cyanide oxidation. Cyanide can be completely oxidized to cyanate with hypochlorite at room temperature in 5 min. Nickel

cyanide was the only exception; it required ½ hr. and 20 per cent excess hypochlorite. Cyanate is completely oxidized to nitrogen and $CO_2$ in about 1 hr. at room temperature. For oxidation to cyanate, the pH should be 10 to 12.5 to avoid formation of cyanogen chloride, but the second stage can be completed at pH 7.5 to 9; as pH increases above 9, oxidation of cyanate decreases rapidly.

At the Seattle plant of Boeing (12), concentrated cyanide waste and all toxic solids are sealed in leak-proof, non-buoyant drums and dropped in the ocean 100 mi. off the continental shelf. Weaker cyanide solutions are treated with calcium hypochlorite in batches. Final waste contains less than 1 p.p.m. Cn and has a pH 6 to 8. A continuous treatment is described by Chamberlin (32). Water from the first rinse tank in a plating line is recirculated at 10 g.p.m. through the injector of a chlorinator. Fresh water flows to the tank at 1 g.p.m. and a like amount goes to the sewer. Caustic solution is added to the recycle line, and a control sounds an alarm if the pH drops below 8.5. The second and third rinse tanks contain negligible cyanide, and sometimes a chlorine residual. There is no chlorine odor, and no spoilage of plated surfaces. A bibliography of papers on cyanide chlorination has been published (6).

The General Motors program and three of its waste cyanide treatment plants are described by Milne, Uhl, Roy, and Hauri (101). The program emphasizes better control to improve efficiency; recovery of chemicals; and development of substitute processes, e.g., gas cyaniding for molten cyanide baths, and acid for cyanide copper plating. At a Diesel engine plant, waste from molten cyanide baths is dissolved in a tank of water with an agitator; chlorine is dispersed directly from a cylinder until a test shows cyanide absent. Pontiac treats 30 lb. cyanide from heat treating, 100 to 150 gal. from zinc plating, and 1,350 gal. from copper plating per week. The wastes are treated separately; chlorine is dispersed directly from a cylinder and the water is recycled until all the cyanide has reacted. Depending on the type of waste, chlorine consumption varies from 3.25 to 7.58 lb. per lb. CN, and up to 6.3 lb. caustic soda has been used. At Delco-Remy, water from the final rinse tank of a zinc-plating line is recirculated at 10 g.p.m. through a chlorinator. Fresh water is added and overflows from the tank at a constant rate. There is pH control, but experience has shown that 80 lb. of caustic per day will hold the pH to 8.5 to 10. Hauri (66) (67) has published additional details of this installation.

Lancy (86) has proposed a method for integrating waste treatment with plating line operation. He suggests automatic plating lines to reduce waste and labor cost. If waste treatment is included as an integral part of such a line, the cost would be about 10 per cent of the investment in productive equipment, or 1 per cent of the cost of a conventional treatment plant. For chromium, he proposes spraying plated work with an alkaline reducing solution, settling the sludge, and recycling the water to the plating tanks. He also suggests ion exchange in a recirculating system to provide de-ionized rinse water; though backwash would need treatment, he claims an over-all economy. For cyanides, he recommends a reservoir equipped for chlorination, and notes that the alkalinity will normally be adequate to maintain pH 8.5. The treated waste would flow to a holding tank providing 1- to 2-day retention before recycling supernatant. Ion exchange is recommended for cyanides because the backwash can be processed for re-use. For acid rinses, he proposes the same kind of recirculating treatment system. He prefers ion exchange where the work must undergo further plating without buffing.

The General Electric waste control

program was reviewed by Watson (156). At Erie, Pa., cyanide rinses receive batch alkaline chlorination; chromium waste is reduced, precipitated, and settled in a Cyclator; concentrated acids are separately neutralized with lime; all sludges are finally combined and vacuum filtered. Details of this plant are given by Townsend (147). At Brockport, N. Y., chromium is reduced, precipitated with soda ash and the sludge lagooned. At Philadelphia, Pa., acid waste is neutralized to pH 5 by recirculation through upflow limestone beds and discharged to a city sewer. Milne (100) has examined waste solutions from several comprehensive metal processing plants for their effects on streams and sewage plant operation. Methods for treating wastes and preventing losses are discussed. Cooper (37) gave a general review of plating waste treatment, including much useful practical and technical advice. A prepared discussion reported that Project 10 of the American Electroplaters' Society will include studies on oxidation of cyanide with chromic acid; acid hydrolysis of cyanide with chromic acid; conditions affecting evolution of HCN; ion exchange; and cyanide treatment with ferrous sulfate and caustic soda. Pyrophosphate baths are not yet available for all metals plated from cyanide baths, and the deposits are not necessarily equivalent.

Ozone was found by Tyler, Maske, Matthews, and Westin (149) to be as effective as chlorine for oxidizing cyanide, and easier to control. They treated cadmium cyanide solutions direct from plating baths with ozone generated in the laboratory. Their equations show that a mol of ozone is required to convert cyanide to cyanate, and 1.5 mols additional is needed for complete destruction. Efficiency was improved by starting treatment at pH 11 to 12; oxidation to cyanate was then complete before the pH fell to 8. An electrolytic method for destroying cyanides was patented to Wagner (155). An electric current is passed through an aqueous cyanide solution at a temperature of 200° F. until the solution is substantially non-toxic.

The Metal Finishing Committee (15) of the Ohio River Valley Water Sanitation Commission plans several manuals; one on plating room controls has been issued (114). First attention should be given to drag-out losses because they account for 60 to 80 per cent of all plating supply costs, exclusive of anodes.

Treatment of chromium wastes by ion exchange was studied by Tyler, Maske, and Westin (150). If trivalent chromium is passed through a bed of Zeo-Karb H, true cation exchange will result through replacement of hydrogen in the sulfonate by chromium. But this resin cannot function as an anion exchanger; if hexavalent chromium is applied, the active carbon in the resin will adsorb the chromate. On acid regeneration, chromium will be reduced, an equivalent amount of carbon oxidized, and some chromium regenerated as an acid salt. This mechanism was confirmed by using Carbo-Dur, an activated carbon of high capacity. Stromquist and Reents (141) applied ion exchange to removal of extraneous ions from a chromium plating bath. These baths pick up metals (Fe, Cu, Zn, etc.) from the parts being plated, and when their concentration reaches 10 to 15 g. per liter the bath must be discarded. Operating a cation exchange resin in the hydrogen cycle at pH 0.7 to 0.8 they were able to remove enough of the contaminating ions to make the bath re-usable. The styrene divinyl benzene resins were found to be most suitable because of their stability under extreme conditions of acidity, alkalinity, oxidation, and temperature. The resin was regenerated with 20 to 25 lb. 66° sulfuric acid per cubic foot, at 10 per cent concentration. Removal of aluminum from anodizing baths is also possible by this technique.

Design and operation of a plant to treat waste water from a metal working

plant was described by Gard, Snavely, and Lemon (52). The wastes contain acid, alkali, zinc, copper, chromium, and cyanides. Sanitary wastes are diverted to the plant sewer; acid wastes containing chromium are collected separately from alkaline wastes containing cyanides, cleaners, and oils. Chromium is reduced with metabisulfite, cyanides oxidized with chlorine, the two wastes combined, the pH raised with lime, and the sludge settled in a Cyclator. Monaweck and Kelly (105) recommend mixing acid and alkaline wastes in a steam-coil heated, agitated tank to pH 4.8 to 9.2; they have tabulated quantities of acids and alkalies required to bring a given waste water within this range. Parsons and Rudolfs (122) state that copper-pyrophosphate baths are increasing in popularity; the baths are rarely discarded, but a typical rinse water might contain 30 p.p.m. Cu, 200 p.p.m. pyrophosphate, 15 p.p.m. citrate, 10 p.p.m. $NO_3$, and 1.5 p.p.m. $NH_3$. High-calcium lime was found to be the best and most economical precipitating agent. Lime was mixed with rinse water for 5 min. and settled 1 hr.; under these conditions the sludge occupied 10 to 15 per cent of the original volume. The sludge concentrates, after 24-hr. settling, to 50 to 70 gal. per gallon of waste. Centrifugation reduces this volume to 10 to 15 gal. The sludge can be dewatered on vacuum or pressure filters if lime is used as a conditioning agent. Total material cost for removing 97 per cent of the copper and leaving no more than 1 p.p.m. unprecipitated, including sludge conditioning, is less than 3.5¢ per 1,000 gal. of waste.

Allowable limits for chromium in drinking water were reviewed by Davids and Lieber (40). They reported a ground-water survey which disclosed up to 40 p.p.m. of chromium originating from anodizing baths at aircraft manufacturing plants. All sources of this pollution were removed by installing copperas and lime treatment. The history of pollution in the Naugatuck River (Conn.) was outlined by Mitchell, Cassanos, and Okun (103). A brief but intensive survey revealed copper and chromium in waste water far in excess of amounts known to interfere with sewage sludge digestion. Vogel and Bloodgood (154) surveyed the literature on toxicity of cyanogen compounds, reporting the minimum lethal dose of HCN for humans to be 50 to 60 mg. if taken at one time, but temporary drinking of water containing up to 18 mg. could be tolerated; 0.3 p.p.m. NaCN did not affect minnows in 24 hr., but 0.5 p.p.m. caused 25 per cent mortality and 0.75 p.p.m. 50 per cent. Trout died in 47 min. in water containing 2.0 p.p.m. NaCN. All plankton died in 30 min. in water containing 200 p.p.m. KCN, but some expired in the same time at a concentration of 40 p.p.m.

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## RADIOACTIVITY

### The Problem

In a preliminary report (31) on the industrial utilization of fission product (a waste from the operation of nuclear reactors) the Stanford Research Institute states that "the U. S. Atomic Energy Commission produces vast quantities—as by-products of plutonium production." Most of the products are stored underground in large concrete vaults and the Atomic Energy Commission has asked the Stanford group to study potential industrial applications. The radiation characteristics and yield of 15 of the radioactive isotopes in fission product are tabulated. The potential uses for killing organisms, controlling biological reproduction, artificial aging of foods, and causing chemical catalytical effects, polymerization, oxidation, and halogenation are briefly discussed. "More than enough fission products are in storage and after processing could supply potential users with 10,000- and even 100,000-curie quantities."

The rapid growth of the industry and present sources of wastes were discussed by Murdock (65), Straub (84), and Emlet (25). *Isotopes* (1), a new publication containing information relative to sources, characteristics, and availability of radioactive elements, was approved for publication April 11, 1951.

The problem of radioactive waste disposal was reviewed (94) (32) (33) (83) (8). Wolman and Gorman (94) concluded that the future growth of the atomic energy industry may well hinge on its ability to find increasingly effective and reasonably economical methods of disposal of its hazardous waste products.

The areas of existing and proposed Atomic Energy Commission facilities were located geographically and Atomic Energy Commission sponsored programs of research and development in waste disposal and environmental sanitation at a dozen centers were outlined by Gorman (32(33), while the total activities of the Atomic Energy Commission program were outlined elsewhere (2).

The decay of gross fission product from the simultaneous slow fission of uranium$^{238}$ and the relative abundance of radioactive elements at any given time after fission from 10 sec. to 100 yr. were recalculated by Hunter and Ballou (41) from the most recent information available. The decay rate is extremely rapid at first and much slower as the product ages. With the passage of time any particular radioactive isotope assumes greater prominence until the growth of daughter isotopes overshadow it. Thus, with age, there is a succession of radioactive elements of different chemical behavior. In the age span of several months to 100 yr., columbium, cerium, cesium, strontium, yttrium, ruthenium, rhenium, barium, lanthanum, praseodymium, and zirconium may be found.

The yield of fission product elements is somewhat different for the fission of thorium$^{232}$ (92), according to radiochemical procedures similar to those developed by the Manhattan Project (15).

## Radiation Safety

The International Commission on Radiological Protection adopted new radiation safety standards with more rigid criteria (44) (45) (46) (47). The maximum permissible surface exposure of the whole body to x-ray and gamma radiation was reduced by one-half to 0.5 r. per week. This roughly corresponds to 0.3 r. per week when measured in free air. In the case of high-energy beta rays, the maximum permissible exposure to the surface of the body in any one week shall not be more than the equivalent energy of 1.5 r. of gamma rays. In the case of fast neutrons, the maximum permissible energy absorption should not be greater than one-tenth of that permitted for high-energy gamma radiation.

The International Commission on Radiation Protection was not "in a position to make firm recommendations regarding the maximum permissible amounts of radioactive isotopes that may be taken into or retained in the body." However, the above radiation safety standard (44) (45) was used to calculate a reasonable maximum permissible value for some of the more important radioactive isotopes. Values were calculated for both air and liquid media. The values given for liquid media in micro-microcurie per milliliter are: 0.04 for radium$^{226}$, 0.8 for strontium$^{90}$ plus yttrium$^{90}$, 1.5 for plutonium$^{239}$, 1.6 for strontium$^{89}$, 10 for cobalt$^{60}$, 30 for iodine$^{131}$, 200 for phosphorus$^{32}$, 800 for sodium$^{24}$ and 400,000 for tritium (44) (46).

The responsibilities and activities of the Subcommittee on Waste Disposal and Decontamination of the National Committee on Radiation Protection were reviewed by Jensen (48). The major isotopes shipped by the Atomic Energy Commission were considered of greatest importance. In order, these isotopes were: $I^{131}$, $P^{32}$, $C^{14}$, $Fe^{55}$, $Fe^{59}$, $Au^{98}$, $Co^{60}$, $Na^{24}$, and $K^{42}$. Research should be directed to biological reconcentration studies and the movement of radioactive materials in soils.

Because it was not realistic to insist on dilution of radioactive waste in sewage to the level established as permissible in drinking water, the Subcommittee on Waste Disposal and

Decontamination of the National Committee on Radiation Protection reviewed the external and internal radiation hazard and recommended raising the maximum permissible level to be discharged in sewers (88) to: (a) a transient (maximum short-period) concentration of 100 microcuries of either isotope per liter of sewage; (b) a single batch discharge of 10 millicuries; and (c) when a uniform discharge device is used, 100 millicuries of these isotopes may be discharged in any 6-hr. daylight period into a system having an average dry-weather flow of 1 m.g.d. Isotopic dilution was considered unnecessary. Restrictions on the total quantity of isotopes and advice on disposal practice were given in detail.

The Subcommittee also released a comprehensive booklet (89) on the maximum permissible levels of radioactive contamination of the skin, clothing, laboratory tools and glassware, work tables, floors, etc.; precaution which should be taken in the safe handling of radioisotopes; emergency measures and procedures to be taken in case of laboratory accidents; and decontaminating methods. This booklet supplements the National Bureau of Standards Handbook No. 42 on the "Safe Handling of Radioactive Isotopes."

## Emergency Measures and Decontamination

A basic disaster plan (61) in the event of atomic attack can do much to save lives and protect non-contaminated personnel. This is a problem for the sanitary engineer. The general picture of types of radiation to be concerned with, their consequences, tolerance limits, and a 10-point check-off list evaluating the vulnerability of water supply systems to attack were described.

An effective disaster plan will require personnel familiar with the basic concepts of health physics (3), radiation monitoring (35), instrumentation, and decontamination.

The practical aspects of radioactivity instruments concerning construction (24), testing, and servicing (55), and calibration (60) of portable meters, ionization chambers, G–M tubes, proportional counting chambers, scintillation counters, and associated electronic assemblies, were reviewed.

Concerning surface decontamination, various types of surfaces from which radioactive material would be easily removed were studied (74) (22) (93). According to Ross (74) smooth, non-porous and nonionic surfaces resistant to corrosion by acids, alkalies, solvents, and heat should be employed and decontaminated with suitable detergents. The Naval Radiological Defense Laboratory (93) listed the advantages and disadvantages of various agents and techniques for decontaminating solid surfaces. The liberal use of water for preflushing and rinsing off acids, detergents, and complexing agents made the methods particularly applicable for ship decontamination on the high seas, where the disposal of contaminated wash and flush waters is of minor importance.

Concerning water contamination, an estimation of the 10-day and 30-day emergency levels of radioactivity in drinking water can be made with the relatively inexpensive beta-gamma survey-type meters used in area monitoring. Hursh, Zizzo, and Dahl (43) presented techniques of procedure and calibration whereby each of the 9 different survey meters tested were found satisfactory for detecting 1 to 90 microcuries of phosphorus$^{32}$ per liter of water. One satisfactory technique consisted of pouring the water to a depth of 1 in. in a metal salve box about 4 in. in diameter, placing the sensitive part of a G–M tube at a fixed distance above the surface and observing the reading on the meter, which previously had been calibrated in terms of microcuries of radioactivity per liter. Activities much less than 1 microcurie per liter can be estimated with survey

meters if the water sample is first evaporated to dryness.

Lauderdale and Emmons (56) (57) reported on an emergency water decontamination system. Two glass-tube columns, each 26 in. in length and having a capacity of approximately 225 ml., were filled with various absorbents and used to remove radioactivity from drinking water. The water was contaminated with 2.5 microcuries of 60-hr.-old fission product per milliliter of Clinch River (Tenn.) tap water adjusted to pH 7.5, and passed at rates up to 5.0 g.p.m. per sq. ft. through successive beds of 15 in. of 0-grade steel wool, 8 in. of burnt clay, 3 in. of activated carbon, and, finally, 26 in. of mixed bed anion-cation exchange resin. Using an effluent radioactivity of 0.1 microcurie per liter as a criterion of satisfactory performance, it was found that: (a) 26 in. of mixed bed resin column used alone delivered 3 l., or 12 volumes, before the effluent was unsatisfactory; and (b) the combination of 26 in. of mixed absorbents followed by 26 in. of mixed bed ion exchanger delivered 28 l., or 50 volumes, before the effluent was unsatisfactory.

The activity was eluted separately from each absorbent and subjected to radiochemical analysis. It was found that the bulk of the ruthenium, zirconium, strontium, cerium, cesium, niobium, tellurium, and rare earths was removed by the steel wool. A relatively high fraction of the activity found in the burnt clay was cesium, strontium, and rare earths. Most of the activity in the cation exchanger was strontium. Most of the activity in the anion exchanger was also strontium and some tellurium.

The ability of various exchange resins to remove the radioactivity of specific isotopes at concentrations of 1,000 to 2,000 counts per minute per ml. of various solutions was tested (49). One of the purposes of these investigations was to develop a laboratory waste disposal unit consisting of a cartridge containing ion exchange resins.

A sample container was constructed (50) that enables the determination of the radioactivity of a liquid flowing through it. The unit consists of a G–M tube mounted on a thin window face of the container.

### Waste Treatment

The general application of various methods of waste treatment were discussed by Straub (84) (85), Rodger (71) (72), Newell and Christenson (66), and Ruchhoft (75). Ion-exchange (6) and evaporation (64) methods were applied to the Knolls Atomic Power laboratory wastes according to Ayres and McCullough, respectively. Carbonate precipitation and double sedimentation was used on the Harwell Laboratory Wastes (4). The laboratory waste treatment by sedimentation, dilution, and dispersion at the Oak Ridge National Laboratory has been changed to that of concentration by evaporation and storage of residues, according to Browder (10). Following laboratory research on chemical precipitation and biological treatment by activated sludge (76) and trickling filter (67) (11), Newell and Christenson (68) reported plant operating results using dual chemical coagulation and sedimentation and then sand filtration for process wastes and high-rate trickling filter treatment for laundry wastes. The process waste plutonium content was reduced from 200 to 25,000 counts per minute per liter of influent to 20 to 200 c.p.m. per liter of filtered effluent.

Comprehensive data on the equipment, engineering, and costs of radioactive waste disposal for the Argonne National Laboratories were reported by Rogers and Fineman (73). Radioactive gases are filtered through a fiberglass prefilter and a paper-asbestos final filter before discharging the decontaminated gases to the atmosphere. Stack gases from the incineration of combustibles first pass through three gas scrubbers before filtration. The liquid wastes are handled in one of

three ways. Very active process wastes are neutralized with lime, mixed with Portland cement, hardened, and shipped to a final storage area. Dilute wastes are collected in 1,500-gal. glass-lined retention tanks and monitored. If the radioactivity is sufficiently low, it is discharged to an outfall sewer, where it is diluted with 0.4 m.g.d. of sanitary sewage. About 80 per cent of the liquid wastes may be discharged without treatment. If the level of radioactivity of the retention tank waste is greater than the maximum permissible for discharge it is pumped into a tank truck and hauled to holding tanks for evaporation or ion exchange treatment. Scaling and foaming troubles in the evaporator have been eliminated by operating with an acidic feed. Wastes with 0.08 per cent solids are evaporated to 45 per cent solids. The beta activity of the condensate did not exceed $7 \times 10^{-4}$ microcurie per liter. The evaporator bottoms are dried in a small stainless steel twin-drum vacuum dryer and the residue is packaged for shipment and final storage. Studies are in progress on the use of resin ion exchangers for decontaminating some low level radioactive wastes, rather than using the evaporation technique.

By simple evaporation, followed by de-entrainment by means of a fiberglass filter, a decontamination factor (influent concentration/effluent concentration) of at least 10,000,000 was achieved for nonvolatile fission product waste solutions (59) from the Brookhaven National Laboratory.

The removal of radioactive contaminants was studied by Straub *et al.* (86) in a 250-g.p.d. experimental rapid sand filter plant and by means of jar tests. Tap water containing about 100 p.p.m. turbidity added as clay slurry was used as raw water and to this was added $P^{32}$, $I^{131}$, or simulated mixed fission product. The raw water was coagulated with 0.65 grains per gallon alum and 0.24 grains per gallon NaOH. Coagulation and sedimentation effected a removal of 85 per cent of $P^{32}$ and 46 per cent mixed fission product. The over-all removal by coagulation, sedimentation, and sand filtration was 96 to 98 per cent for $P^{32}$, less than 0.4 per cent for $I^{131}$, and 70 to 73 per cent for mixed fission product. Jar tests indicated wide variation of removals, depending on kind and amounts of reagents used. $Na_2CO_3$ gave better removal for $Y^{91}$ than NaOH. According to Lauderdale (58), and the Morton-Placak Group (87) (26), phosphate and lime treatment for di- and tri-valent cations was quite effective at a pH greater than 11.3. High removals of $Ce^{144}$ and $Sr^{89}$ were also obtained by passage through a column of burnt clay.

Laboratory studies on the fate of $Na^{24}$ and $Co^{60}$ as cations, of $I^{131}$ and $Br^{82}$ as halides, and $P^{32}$ as phosphate in sewage treatment by plain sedimentation, trickling filters, and activated sludge, were reported by Belcher (7). The sewage was dosed with 0.5 to 50 microcuries of isotopes per liter. Removals by plain sedimentation were small (1 to 5 per cent) for all isotopes. Removal of $I^{131}$, $Br^{82}$, and $Na^{24}$ by either trickling filters or activated sludge was also small (3 to 20 per cent), whereas removal of $P^{32}$ and $Co^{60}$ by secondary treatment was greater (77 to 88 per cent). The dosing of a trickling filter with 100 microcuries of $P^{32}$ per liter of settled sewage for 24 hr. failed to produce radiation effects that significantly altered the effluent indices—B.O.D., $NH_3$-N, $NO_2$-N, $NO_3$-N, or oxygen absorbed values.

According to Grune and Eliassen (37), radioactive phosphorus, when present in concentrations at or below 10 millicuries per liter, exerted no significant effect on the first-stage B.O.D. of sewage.

In laboratory studies at the Massachusetts Institute of Technology (23), simulated natural surface waters contaminated with $I^{131}$, $P^{32}$, or $Sr^{89}$ were treated similar to conventional water treatment processes, using alum, ferric

sulfate, lime-soda, or lime-phosphate coagulants. The success of treatment depended on the raw-water quality, the radioactive contaminant, and the treatment process used. More than 99 per cent of the strontium was removed by the lime-soda softening or the phosphate-lime coagulation process.

After examining the amounts of iodine$^{131}$ and phosphorous$^{32}$ distributed to large centers of population in the United States, it was concluded by Ruchhoft and Feitelberg (77) that the probability seemed remote that any one hospital would discharge regularly as much as 200 millicuries of waste per day into the sewage of a large city. At this rate, the dilution needed to reduce the activity to safe limits was no major problem. A simple, constant-level, fixed-orifice device for discharging liquid wastes to the sewer at a uniform rate, as suggested in the National Bureau of Standards Handbook No. 49 (88), was recommended for preventing excessive concentrations in the sewers. Calculations indicated that the hazard from sewage plant fertilizer would be quite remote. For example, the radioactivity of the filter cake fertilizer from digested sludge produced in a 12.5-m.g.d. primary sewage plant might be as much as 0.25 microcurie per kilogram only if the sewage flow received a daily discharge of 1,000 millicuries of iodine$^{131}$.

## Incineration and the Stack Gas Problem

A radioactive waste incinerator for contaminated combustibles was designed (5) following experimental work on the choice of scrubbing solution and the efficiency of various methods of dust collection.

Radioactive particulate matter in the stack gases from the incineration of contaminated combustible wastes was experimentally decontaminated by Schauer (80). High efficiency of decontamination was obtained by introducing the gas stream into a steam exhauster. Condensing water droplets increased the size of particulate matter, which then could be removed by conventional gas-scrubbing equipment.

It was found that, in the incineration of combustible laboratory wastes containing radioisotopes, the fluxing of the radioactive residues with molten NaOH was a safe means of disposal (13).

A comprehensive two-volume report (9) on the experimental studies conducted with three types of glass fiber for decontaminating radioactive aerosols was released.

## Biological Effects

A survey was made of the radioactivity of fish collected from fresh water which received radioactive industrial wastes (51). Fish collections were made from White Oak Lake and three embayments of the TVA Watts Bar Reservoir on the Clinch River 0.2, 2.5, and 8 mi. below White Oak Dam. Samples of flesh, bone, and scales were assayed for radioactivity (52). In general, the bone was more radioactive than the flesh by a factor of 7 to 10 and the scales were more radioactive than the flesh by a factor of 10 to 20 on a unit weight basis at each collection point. In general, the flesh of the White Oak Lake fish was roughly 10 times as radioactive as the flesh of the radioactive specimens just below the dam, 40 times as radioactive as the flesh of the radioactive specimens found 2.5 mi. downstream, and 50 times as radioactive as the flesh of the radioactive specimens found 8 mi. downstream. However, only the most radioactive specimens at the lower collection stations, representing less than 10 per cent of the total catch, were assayed. Radiochemical analysis indicated that, of the radioactivity in the flesh, 96.8 per cent was due to cesium$^{137}$, 1.7 per cent was due to strontium$^{89}$ and strontium$^{90}$, and 1.5 per cent was due to yttrium$^{90}$. The bone and scale radioactivity was largely strontium$^{90}$ and its daughter, yttrium$^{90}$. The human consumption of 2.5 to 10 oz. of flesh from

fish in the most radioactive water (White Oak Lake) contained sufficient strontium radioactivity to exceed the daily "maximum permissible" dosage. The health hazard from the ingestion of bone or the solution of strontium from bone when fish is prepared for the table was not considered.

From a laboratory investigation of the uptake of $I^{131}$ by heterogeneous bacterial slimes, Talboys (90) found there was little tendency for $I^{131}$ as the iodide to concentrate in the slimes of sewer drains. It was concluded that the resultant hazard to maintenance workers who may contact the contaminated slimes would be very low.

Two groups of rats drank only nuclear reactor cooling water effluent, adjusted to either 3 or 300 micro-microcuries of radioactivity per milliliter for periods of 200 to 500 days (39). Growth rate of the experimental rats was not affected by the radioactivity, and no histological changes were observed. In this group which drank the greater concentration, the blood and kidneys usually had the highest specific activity of about 20 micro-microcuries of $Na^{24}$ and $P^{32}$ per gram. It was concluded that the hazard to mammals drinking Columbia River water containing diluted cooling water was negligible if the diet provided all the essential elements.

A study of the urinary elimination of radioactivity following an incident in which an individual became contaminated with strontium$^{90}$ was reported (16).

## Natural (Background) Radioactivity

The various components of background radiation and the various naturally occurring radioactive substances were described (17) in a semiquantitative manner in connection with problems of radioactive waste disposal, etc.

Water samples (source and tap) were collected from 18 cities in the western part of the United States and measured for radium content (42). The radium content of the source water ranged from about 0.03 to 2.0 micro-microcuries per liter and for the tap water from about 0.03 to 0.3 micro-microcuries per liter.

In an investigation of the radium content of common foods, the radium content of fresh, dried, and commercial powdered milk has been determined to be between 1 and 4 micro-microcuries per kilogram of dried milk solids (79), or 0.1 to 0.033 as much as reported by Burkser *et al.*[*]

Amounts of radioactivity reported in hot springs and spas throughout the world have been assembled on a geographical basis (63).

Radioactive clouds were investigated by airplane (30). The activity was reported in equivalents of radon. The maximum concentration found on June 11, 1950, was 0.01 micro-microcuries per cubic meter at elevation 2,000 meters; on January 13, 1951, 0.03 at elevation 4,000 meters; on February 3, 1951, 0.15 at elevation 4,100 meters. The activity had a half life of 20 to 50 hr. On February 7, 1951, following precipitation, the atmosphere was essentially free of activity. The origin of active clouds (either from atomic explosion or by derivation from its products), the fallout factor, and condensation nuclei were considered.

## Analytical Methods

The radiochemical studies of the fission products by the plutonium project of the Manhattan District, consisting of 336 papers, were edited by Coryell and Sugarman (14).

Detection methods available for the investigation of radiocolloids, the theory of their formation, nature, and applications were reviewed (81). The results obtained by various investigators were summarized concerning the radiocolloidal behavior of Po, Bi, Pb, Th, Y, Zr, Nb, La, Np, Pu, Pa, Mg, Se, Sn, Ti, Ce, Be, and Ba.

The radiochemistry of separating $I^{131}$

[*] *Biochem. Zeit.*, **211**, 323 (1929).

and uranium from waste solution and the problems of absolute counting of alpha or beta radioactivity were considered in detail (27).

In determining radioactive iodine in fluid or tissue (70), the sample was treated with $KMnO_4$ and concentrated $H_2SO_4$ and distilled. The iodine was collected in lithium arsenite solution and an aliquot evaporated for counting with an end-window counter.

A simple process has been devised for the recovery of $I^{131}$ from the urine of treated patients (19). The process consists of $AgNO_3$ precipitation, followed by bromination of the residue to iodate, pH adjustment, and final purification by distillation if desired.

Chemical techniques for sample preparation, construction, and operation of an ionization chamber and electronic equipment were described by Hudgens *et al.* (40) for the determination of as little as $10^{-14}$ gram of radium per gram of sample from a measurement of the radon, which was allowed to grow into partial or total equilibrium with the radium.

A method for determining polonium in biological samples was described (78). The method consists of wet oxidation and coprecipitation with tellurium. The polonium is then separated from tellurium and deposited on one side of silver foil for counting. A recovery of 85 per cent and a sensitivity of 1 micro-microcurie from urine were reported.

In separating and estimating one of the more hazardous radioactive fission products, strontium, in water and urine, Mawson and Fischer (62) investigated the methods of Tompkins, Farabee, and Khym (1949) and Kallmann (1948), and proposed a modification consisting of coprecipitation with calcium or other carriers as the oxalate (Sulkowitch reagent) at pH 4.0. Recoveries of 70 to 100 per cent were obtained from 750 ml. of urine to which had been added 5 to 12 counts per minute.

A relatively inexpensive apparatus for the simultaneous electroplating of up to 12 samples of material was described (21). Various kinds of cathodes were listed and procedures for the determination of Cu, Ag, Zn, Hg, Fe, and Co were given.

A method was described (36) for the recovery of 37-yr. cesium$^{137}$ from alkaline waste solutions by cocrystallization with potassium aluminum sulfate.

Paper chromatography was used to separate inorganic radioactive ions, such as Fe from Co; Pb, Bi, and Po from each other; Mn from Zn; and Na from K (29). A Geiger tube was used to locate the chromatographed element and, by counting rate and decay, to determine the isotope and relative abundance.

Fletcher (28) studied the factors involved in the "direct" fluorometric determination of uranium in the range of 0.005 to 0.08 micrograms of U. Reproducible results could be obtained by fusing at 650° C. for 25 min. using a carbonate-fluoride flux. Kolthoff and Johnson (53) determined $UO_2$, Th, Zr, and Sn (IV) by titrating with *m*-nitrophenylarsonic acid amperometrically.

### Instrumentation

For monitoring the radioactivity in 500-ml. samples of sewage at the Brookhaven National Laboratory by the evaporation method, Cowan and Nehemias (18) concluded that the minimum detectable amount for $P^{32}$ and $C^{14}$ was 16 and 180 micro-microcuries per liter. Using 200 ml. of sewage to minimize self-absorption, the minimum detectable amount of polonium alpha activity was 3.0 micro-microcuries per liter.

A comparative study of the relative sensitivity of a thin mica end-window counter, a windowless G-M flow counter, and a windowless proportional counter was made by Graf, Comar, and Whitney (34). Internal counters were found to be 3 to 30 times more sensi-

tive than end-window counters, depending on the energy of the 10 beta-emitting isotopes tested. Absorption data for 0 to 3 mg. per sq. cm. were presented for $C^{14}$, $S^{35}$, and $Ca^{45}$.

For efficient counting in a G-M end-window counting set, Cook *et al.* (12) advise that the diameter of the sample on a tray be less than one-half the diameter of the end-window and placed a distance from the window either not exceeding 0.1 the diameter of the window or more than the diameter of the window.

The development of a simple automatic sample changer which can be used with windowless gas flow counter tubes for the measurement of alpha or soft beta particles was described (69).

A scintillation probe was developed (20) for counting alpha radioactivity and the self-absorption of beta radioactivity was evaluated by two different methods (82).

The alpha and beta activity of air was monitored continuously (54) by deposition of air dust on a strip of filter paper moving at the rate of about 1 in. per hour across an aperture through which air was pumped. The strip of paper, after collection of the dust, passed in front of one or more counters.

Taplin, Douglas, and Sanchez (91) have improved their two-phase chloroform-dye indicator system for gamma radiation measurements by removing the alcohol preservative in the chloroform and thereby gaining sensitivity to within the 10- to 100-roentgen dosage range. By reducing the concentration of the dye and adjusting the pH closer to the yellow end point in alcohol-free systems, doses of one roentgen or less may be detected colorimetrically. The method is, however, wave length and temperature dependent.

Grune and Klevin (38) described the laboratory equipment and techniques used in studying the effect of up to 10 microcuries of $P^{32}$ or $I^{131}$ per milliliter of dilution water on the B.O.D. of sewage.

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## WATER POLLUTION

### Abatement and Control

Numerous articles dealing with the general problem of abatement and control of water pollution have appeared in the literature. Hedgepeth (120) reviews pollution abatement activities and states that cooperative efforts of industry, government, and others can produce a solution for the problems. Murdock (171) discusses the problem of conflicting interests of water users and concludes that it is the responsibility of the state to exercise its powers of legislation and enforcement to protect the public health and safety. Hollis (130) briefly reviews the history, present status, and future requirements of waste treatment and stream sanitation. The responsibilities of industry in the accomplishment of stream pollution abatement are described by Cox (87). Nord (175) stresses the need for an educational approach to the problem of stream pollution and discusses the psychology, technology, and economics of pollution abatement.

Howson *et al.* (132) summarize the critical problem of water supply and stream pollution. The factors responsible for water shortage and the disposal of oil field brines, coal processing wastes, and mine acid are discussed. The authors present a comprehensive summary of water pollution control policy. A policy for pollution abatement is also discussed by Camp (82). The capacity of streams for self purification and the contamination of ground water by industrial wastes are considered. Pugh (199) discusses ground-water protection and controlled discharge of impounded flood waters. He briefly summarizes the research activities of the Institution of Water Engineers.

The federal water pollution control program and recent and proposed legislation concerning pollution control are described by Pond (188). The status of water pollution abatement in the United States is summarized by Hollis (129). He discusses the trend toward the organization of state water pollution control agencies including representation for all major interests. A national summary of water pollution, the first of the Water Pollution Series being produced in compliance with the Water Pollution Control Act (Public Law 845, 80th Congress), by the Public Health Service, Division of Water Pollution Control, was published (189). Several articles discussing this report appeared in the literature (7) (23) (49). The report indicates that the construction of required new or improved waste treatment facilities for some 10,000 municipal and industrial sources of pollution will require the investment of $9 to $12 billions over the next decade. Other reports in the Public Health Service Water Pollution Series which have been released are the summary reports for the following major drainage basins: California Drainage Basins (193), Colorado Drainage Basin (196), Great Basin Drainage Basin (192), Missouri River Drainage Basin (191), New England Drainage Basins (195), North Atlantic Drainage Basins (197), Pacific Northwest Drainage Basins (194), and Tennessee River Drainage Basin (190). These cooperative state-federal reports present information as of July, 1950, concerning pollution being discharged to the streams of the basins, the damages resulting from this pollution, the benefits which may accrue as a result of pollution prevention and abatement, the pollution prevention measures in effect, and the pollution prevention measures required. Of the several articles discussing these reports (4) (21) (32) (48) (203) (232), most elaborate on the reported number of waste treatment facilities required and the estimated costs of these facilities.

The Third Annual Report of the Ohio River Valley Water Sanitation Commission (178) reviews the activities of this 8-state commission and describes the projects undertaken, the progress made, and the pollution abate-

ment objectives of the Commission. Of significance to all interstate commissions was a decision of the U. S. Supreme Court which verified the constitutionality of this Compact, reversing an opinion by the West Virginia Court of Appeals that the agreement was in violation of the West Virginia Constitution (51). Articles dealing with activities of the Commission describe the progress made in the municipal and industrial pollution abatement programs in the Ohio Basin (14)(29)(43).

Vermont (59) and New Hampshire (52) have joined Connecticut, Massachusetts, New York, and Rhode Island as official members of the New England Water Control Commission. The Interstate Sanitation Commission (New York, New Jersey, and Connecticut) has reported on its activities for 1950 (136). The first phase of an Interstate Sanitation Commission investigation of the industrial waste problem along the 1,500-mi. Connecticut, New York, and New Jersey coastline has been reported (39). It was disclosed that some 300 industrial plants discharge a total waste load of more than 500 m.g.d., approximately one-fifth of this being discharged into recreational waters. Recent progress made on the Potomac River pollution abatement program is reported (37).

Bacon (62) discusses California's pollution control legislation defining areas of jurisdiction by state agencies. The organization of boards to apply this legislation and a tentative water quality criteria report are described by Grayson (117). Favorable results for the first year of operation of California's pollution control plan have been reported (26). The progress of the Water Pollution Control Board in the establishment of water quality standards for catchment areas, plains and valleys, and coastal areas is reported (42). A method for the analysis of waste problems to determine degrees of waste treatment required is included.

The completion of treatment plans at Bridgeport and Waterbury, Conn., will bring to 90 per cent the portion of Connecticut's sewage flow which is treated prior to discharge (13). It is estimated that these facilities will cut by more than 60 per cent the pollution of the state's coastal and inland waters.

The major points of interest in the development (9)(17) and enactment (20) of the North Carolina stream sanitation law by the state legislature are reported. The law provides for an 8-man Stream Sanitation Committee, which is to operate under the jurisdiction of the State Board of Health. All bodies of water within the state will be classified and a permit will be required for new waste discharges. The appointment of six members of the North Carolina Stream Sanitation Committee is reported and that part of the law defining the powers and limitations of this Committee is discussed (33).

The Ohio legislature enacted a new pollution control law, to become operative in September, 1952. The steps leading up to its passage and the provisions of the law have been summarized (31). Seven bills concerning stream classification were introduced in the New Hampshire legislature and six bills concerning a study of sewage and industrial wastes in streams of the state were introduced in the Massachusetts legislature (18).

Activity by several states concerning the fight against pollution of water supplies is reviewed (25). This same article describes the Ohio State Department of Natural Resources survey of Lake Erie bathing beaches and reports that Pennsylvania has ordered a number of coal mine operators to suspend the discharge of acid mine waters into streams of the state. Gillenwater (116) discusses the problem of coal washery wastes in West Virginia and reviews means for abatement. The State of West Virginia is currently making a survey to determine the scope of this problem.

Thirty cities in Ohio, mostly in the Mahoning and Miami River valleys and the Lake Erie region, have been ordered to begin activities for provision of sewage treatment facilities (34). The Virginia State Water Control Board ordered the city of Alexandria to provide treatment for its sewage discharged to the Potomac River (10). Following the reduction of pollution of the Schuylkill River by silt and coal fines, the Sanitary Water Board of Pennsylvania ordered municipalities discharging wastes to that river to increase their degree of sewage treatment (28). The Sanitary Water Board of Pennsylvania also acted concerning coal mine operators not complying with regulations on the discharge of acid mine wastes and initiated experiments to make the regulations more effective (35).

The stream pollution control program of Tennessee is described by Farrell (105), that of Texas by Smallhorst (215), and that of Wisconsin by Wisniewski and Muegge (247). Bacon, DeMartini, and Harris (63) summarize the pollution control statutes of Arizona, California, Idaho, Montana, Nevada, Oregon, Utah, Washington, and Wyoming as they apply to the discharge of industrial wastes.

Smith, Moody, and Leifee (219) summarize a legal study of court decisions on the use of the waters of a public stream. The trend in public opinion demanding more and more protection for the riparian owners along public streams is reflected in the decisions of the courts. The need for uniform state pollution control laws and the model pollution control act by the Public Health Service are discussed in an editorial (58). The "Suggested State Water Pollution Control Act" was prepared by the Division of Water Pollution Control, Public Health Service, and critically reviewed by experts from state pollution control agencies (50). The Council of State Governments has endorsed the suggested act and recommends it to the states for their favorable consideration.

The history of federal anti-pollution legislation, from the protection of navigation in 1886 to the comprehensive pollution control legislation of 1948, is reviewed by Murdock (167). Babbitt (61) reports that the administration of stream pollution prevention programs is in a state of flux throughout the country at the present time. Recent and contemplated changes in legislation concerning control programs have prevented stabilization of administrative practices in many states.

The text of the law, enacted in March 1950, for the prevention of water pollution in Belgium has been reported (53).

Progress in the abatement of pollution of Puget Sound (27), in the sewage disposal program in Allegheny County, Pa. (19), and in the construction of sewerage and treatment facilities for Covington, Ky., and surrounding communities (57) is reported. Progress on the silt removal project on the Schuylkill River, Pa., on the pollution abatement program for the upper Wisconsin River, Wis., and on the construction of sewage projects in Illinois are reviewed (22).

Hammann (119) describes the procedure and equipment used in the interim disinfection through chlorination of mixed domestic and industrial wastes being discharged while new treatment facilities are being constructed for the Blackstone Valley Sewer District in Rhode Island.

A steady decrease during the past 20 years in turbidity of Chattahoochee River waters above the Atlanta, Ga., water supply intake is reported (12). This improvement is credited to better land use practices in the watershed area.

The need for efficient operation of sewage treatment plants discharging effluents into surface waters is emphasized by Heuvelen (125).

Sewage plant effluent from 42 California cities and towns is now being

used as irrigation water (40). Plans are also being formulated for the use of activated sludge effluent as industrial water and for the recharging of ground-water strata.

The report by the International Joint Commission on the pollution of boundary waters has been approved by the Governments of the United States and Canada. Certain of the recommendations contained in the report and a cost breakdown for the $127,000,000 abatement program are reported (36).

Four task groups of the National Technical Task Committee on Industrial Wastes reported definite progress toward the more effective control of wastes (8)(16). The four groups reporting represented food industries, mineral products industries, chemical process industries, and general industries.

Some of the important topics discussed at the Sixth Annual Industrial Waste Conference at Purdue University are reviewed (15). One suggestion offered at this meeting was that polluters help finance waste research by means of fees for permits to discharge wastes.

The decreasing adequacy of water supplies and the increasing amounts of wastes have led to more critical evaluations of industrial effluents. One article lists a number of examples of successful recovery of by-products from wastes (5). The activity has resulted in the conservation of water, a decrease in pollution, and less economic loss.

The general problem of controlling the pollution of streams by industrial wastes is discussed by Steel (223) with reference to the work of the Public Health Service. Physical, chemical, and biological pollution by industrial wastes are discussed, and methods of waste treatment are reviewed, in articles by Reignier (204), Nord (176), and Ford (109). Miller (159) describes the problems in waste disposal brought about by the wide dispersal of industry in Indiana. The general problem of stream pollution by the textile industry in New England is discussed by McCarthy (157). He states that, in general, textile wastes may be treated satisfactorily on trickling filters. Hedgepeth (121) emphasizes that to control the pollution of streams by industrial wastes, no set of rules is universally applicable; each case must be considered as an individual problem.

Soet (220), York (255), and Radcliffe (201) discuss the relationship between air pollution and water pollution. Only during the past few years has the general public become aware of the problem of air pollution. The economical control of some types of air pollution is not now possible and much research is needed in the field.

The importance of adapting treatment and disposal of industrial wastes to the capacities of the surface streams into which they are being discharged is stressed by Mohlman (160). He also considers some of the methods used for the treatment of trade wastes. Jacobs (137) suggests that consideration of the receiving stream may indicate that it has adequate capacity to assimilate an anticipated waste load without adverse effects. If waste treatment is indicated, however, he suggests that only treatment sufficient to permit the stream to meet the requisites set for it should be provided.

Hedgepeth (122) discusses the perplexing problem of wastes which do not respond to known treatment. He outlines four fundamental concepts which must be considered in pollution prevention: (a) proper plant location; (b) manufacturing process selection; (c) manufacturing process control; and (d) treatment of effluents to make them safe for stream assimilation.

The effects on streams and sewage treatment plants of waste fiber from paper mills is discussed by Nemerow (173). He points out that fiber losses at some plants may be as great as 25 per cent and suggests means of re-

ducing this loss. Two pulp mills, ordered to discontinue waste disposal practices leading to the pollution of Puget Sound, reached an interim agreement with the Washington State Pollution Control Commission by providing a pipeline for the discharge of their wastes at a point 300 ft. deep and 4,000 ft. offshore in the Sound (11) (41).

The problem of stream pollution as it affects the tanning and leather industry is discussed by Thorstensen (231). The effects of tannery effluents on the receiving stream are described and methods for the treatment of these wastes are suggested by Bergamin (68). Vrijburg (238) discusses the problem of disposal of waste acid and wash water from metal pickling processes. Dougan and Bell (101) report significant pollution reduction through treatment of wastes from a synthetic rubber plant.

Process modifications to reduce waste volumes from a large synthetic organic chemicals plant and the treatment applied to these wastes are described by Lyon (155). McCracken (158) reports the abatement of pollution brought about by the discharge of oxygen-consuming wastes from a chemical plant. Abatement was accomplished through process changes alone, no waste treatment being needed to restore the stream to a satisfactory condition. Murdock (170) reports that the elimination of obnoxious constituents from the waste of a dyeing operation improved the quality of the effluent from a textile manufacturing plant sufficiently to permit assimilation by the receiving stream. The alleviation of a local stream pollution problem by applying the calcium hypochlorite process for the treatment of wool scouring waste is described by Cameron (81). He reports that under optimum conditions a B.O.D. reduction of 90 per cent can be attained.

The du Pont Company's policy of providing for waste treatment facilities in all new plant construction is discussed by De Ropp (97). Treatment facilities for all wastes are being incorporated in the construction of the company's new nylon intermediates plant in Victoria, Tex.

The British River Boards Act, 1948, is discussed by Mosley (163) and by Savage (209). Hobday and Southgate (127) discuss legal and technical aspects of some stream pollution prevention measures with reference to the powers of the River Boards. The more recent Rivers (Prevention of Pollution) Bill equips the River Boards, created by the 1948 Act, with adequate legal powers and clears the way for the rehabilitation of England's streams (46).

In contrast to the lag in the construction of waste treatment facilities in England, research in the fields of sewage and industrial wastes treatment has been active, and the revision of the Ministry of Health "Standard Methods" for analysis is being accomplished by a joint committee of interested bodies (44). Industry and government are cooperating in providing information necessary to deal with the problems of industrial effluents (45). Garner (115) reviews the general progress in research, analytical methods, and pollution prevention for the period since 1922.

The condition of the River Ribble and its tributaries is discussed in the annual report of the Ribble Board of Conservators (54). Specific instances of pollution are cited.

The problems encountered in the discharge of wastes to the sea through submarine outfalls in Holland are discussed by Hopmans (131). Unfavorable winds and sea currents cause pollution of beaches, even though outfalls are submerged at distances of 1 to 2 mi. at sea. A method of calculation to determine whether wastes may be satisfactorily disposed of by discharge to estuaries is proposed.

## Bacteriology

The Ohio River Water Sanitation Commission (38) adopted bacterial

quality objectives for the Ohio River. For domestic use the limit is 5,000 coliforms per 100 ml. (monthly arithmetical average M.P.N.) in any month. The limit must not be exceeded in more than 20 per cent of samples examined per month, nor should a count of 20,000 per 100 ml. be exceeded in more than 5 per cent of samples.

Results of a survey of streams and bathing beaches at Cleveland (96) in 1949 showed the pollution substantially higher than when previously determined in 1939 to 1941. Pollution of the lake water is increasing and is derived from storm-water overflows and heavily polluted streams.

Subrahmanyan and Bhaskaran (229) have reported the results of experiments to determine the extent of pollution diffusing from bored latrines. The distance pollution travels from bored latrines to ground waters depends mainly on the velocity of groundwater flow. The velocity of flow depends largely on the soil structure, but also on the gradient of the water-table. The safe distance between a borehole latrine or leaching cess pit and a ground-water source may be taken as the distance represented by about 8 days travel of the ground water.

The longevity of coliform organisms, *Salmonella typhosa*, and enterococci in soil is prolonged with an increase in organic content of the soil, as found by Mallmann and Litsky (156). Coliform organisms persisted in soil for long periods, enterococci died out rapidly, and virulent typhoid bacilli died out more rapidly than enterococci. The only organisms, other than the coliforms, found in sewage that could be used as indicators of fecal contamination were the enterococci.

Akerlindh (2) investigated the hypothesis that there is a proportionality between bacterial pollution entering a stream and the resulting bacterial density at continuous pollution. His results showed that with only a single dosage of pollution there was a proportionality between the added number of bacteria and the residual bacterial density remaining after various periods of incubation up to 72 hr. Similar results were obtained from continuous feeding experiments.

Following the chlorination of settled sewage Heukelekian (124) found that: (a) there is a significant increase in the number of coliform organisms when the chlorinated sewage is diluted with unpolluted waters (that is, stream or distilled water); (b) the increase is greater in higher concentrations of sewage; (c) the increase is greater when sewage is chlorinated to a higher residual than with lower residuals; and (d) there is no material increase in coliform organisms when chlorinated sewage is diluted with sea water.

Weiss (244) demonstrated that turbidities usually encountered in natural waters affect the *E. coli* content by adsorption of the bacteria on the particulate matter. The degree of adsorption is characteristic of the origin and particle size of the silt. Adsorption to silt particles increases the rate of sedimentation of bacterial cells. Diluted sea water increases the rate of flocculation of silts.

It has been shown by Tubiash (235) that nitrate and nitrite ions in very small amounts exert an inhibitory effect on the production of gas from lactose broth by members of the coliform group. Anaerogenic levels range from 30 p.p.m. to 60 p.p.m. nitrate or nitrite nitrogen against representative strains of *E. coli*. *A. aerogenes* is able to produce gas from lactose broth in the presence of slightly greater nitrogen levels, whereas *A. cloacae* appears more sensitive to the presence of these ions. Nitrates in drinking water at levels which occur not infrequently may be responsible for bacteriologically false-negative reports for the presence of the coliform group.

Clark *et al.* (85) have shown that examinations of water by procedures using the membrane filter give results comparable to the coliform M.P.N. of

Standard Methods "confirmed test" and to the "agar plate count" of Standard Methods. The filtration method has a marked advantage over the standard plate count method for the enumeration of bacteria in samples of low bacterial density. It is recommended for the counting of bacteria in relatively clear waters with high or low bacterial densities and in turbid waters of high bacterial populations. Using a modified Endo broth the membrane filter procedure has the advantage of large samples, minimum time for testing (16 to 18 hr.), and marked reduction in labor, equipment, space, and material. A method for the rapid isolation of *S. typhosa* from large samples is also described.

The results of bacteriological analysis of water supplies for farms and creameries in Wales has been discussed by Franklin and George (111). There is a close correlation between the presumptive coliform content and the presence of milk-souring organisms, although 30 per cent of the samples containing no coliform organisms contained other types of milk-souring bacteria. Few samples of water containing large numbers of coliform organisms did not cause active fermentation of milk. This indicates that the coliform test can be used as an indication of the suitability of a water supply for dairy purposes.

Laurell and Lofstrom (146) have described an epidemiological investigation of epidemic hepatitis in a small community of Sweden in 1945 to 1947. Fifty-six cases of the disease occurred. Good evidence was obtained that the water supply was the source of infection.

When sewage from three tuberculosis sanatoria was examined by Vahlne (237), virulent tubercle bacilli could regularly be recovered by guinea pig inoculation. The sewage from one of the sanatoria was treated in contact beds, from the other two only in sedimentation tanks. In rivers receiving sewage from these sanatoria virulent tubercle bacteria could be found as far down stream as 2,000 m. from the outflow of the sewage.

## Biology

Huet (133) discusses the pollution of water by dissolved and suspended matter; the effects of pollution on aquatic life, especially fish; and the physical, chemical, and biological examination of water. Biological analysis is based on the knowledge that various types of pollution often stimulate the growth of characteristic organisms. Liebmann (150) believes that when organisms are used as indicators of water quality, the whole biological community must be considered. The presence or absence of many species is used to classify water into four major quality groups. The effects of pollution by sewage, industrial wastes, and silt on the productivity and recreational uses of streams is discussed by Cooksey (86). Industrial wastes innocuous to humans may affect adversely the biology of the stream. Sewage in small quantities will not destroy fish or other organisms, but large amounts of sewage will reduce the dissolved oxygen until it will no longer support life.

Doudoroff (99) states that the biological studies of industrial pollution should be directed toward reliable estimation and understanding of the effect of pollutants on important aquatic resources. This objective cannot be achieved through physical and chemical examination of the wastes or the receiving waters, or through studies of those organisms of no immediate value to man and considered only as indicators of stream condition. A direct approach to the evaluation of fish habitats and their productivity is recommended, and comparative studies of fish populations and fishing success in comparable polluted and unpolluted waters are pertinent. Studies of the bottom fauna and of plankton also can be very instructive, but the relative importance of these organisms as food for desirable fish species should be considered.

Toxicity bio-assays of industrial wastes help to explain and to predict the effects of industrial pollution and of remedial measures.

A clean stream is defined by Czensny (88) as one in which the normal fish fauna is able to live and breed, the composition of the fish food organisms has not been changed or diminished in number, and nothing interferes with fishing operations. The effects of different types of pollution on the fish, on fish food organisms, and on fisheries are discussed. It is concluded that the absence of fish typical of the stream can indicate pollution.

Doudoroff and committee (100) outlined a comprehensive procedure for the evaluation of the toxicity of industrial wastes to fish. Not only are details given for routine bio-assay procedures, but auxiliary methods for the testing of wastes with volatile toxic components and high B.O.D. are discussed. In three appendices, suggestions for the care and feeding of test fish, the design of experiments, and the methods of evaluation of test results are given. A brief bio-assay procedure is outlined by Daugherty (90) to measure the toxicity of industrial wastes to marine fish.

LeClerc and Devlaminck (147) suggest certain preliminary stipulations concerning the types of waters used, the comparative duration of tests, appropriate techniques, and the methods of representation of tests used to determine the toxicity of wastes to fish. Wuhrmann and Woker (251) studied the variability of the reactions of test fish in toxic solutions in order to determine valid statistical procedures. To secure average values with less than 20 per cent deviation from the most probable mean for the concentrations tested, at least 5 fish per assay are required. For more reliable comparative tests, at least 10 individuals are required.

Huet (134) discusses the various ways in which toxic substances may affect fish, describes methods used in determining toxicity, factors affecting the results of tests for toxicity, and symbols for use in expressing results. The toxicities of some common substances are given; these include mineral and organic acids, water of high alkalinity, metals, concrete, sodium and calcium chlorides, ammonia, chlorine, arsenic, artificial fertilizers, products from the distillation of tar and petroleum, nicotine, natural resins, pyrethrum, saponin, picrotoxin, and substances secreted by mollusks.

Woker and Wuhrmann (248) tested the sensitivity of several fish species to ammonia, HCN, and phenol. Minnows were more sensitive to ammonia than trout; on the other hand, trout were more sensitive to phenol than minnows. It was concluded that fish used to highly oxygenated waters should not be regarded as always more sensitive to toxicants than fish adapted to oxygen-poor waters. Each species of fish has its own toxicity spectrum.

Kasai (140) studied the animal communities in the acid streams of Japan. The principal characteristic of these rivers is the paucity of animals, especially aquatic insects. The changes in the composition of the animal communities at the confluence of acid streams with normal streams is described. Arnold and Royce (60) investigated the effect on bottom fauna and fish of the disposal at sea of about 3,000 tons per day of a solution of sulfuric acid and ferrous sulfate. Preliminary observations showed that the waste mixed with and was buffered by the upper 50 ft. of the sea water. Surveys of the dumping area and of a control area failed to show significant changes in the animal populations of the two areas and it was shown that bottom animals were not completely destroyed by these wastes even immediately below the point of discharge.

Redfield and Walford (202) made a report on the effect of disposal of acid ferrous sulfate at sea. They found that the waste reacts rapidly with the sea water, forming inert materials. These

remain in solution or in fine suspensions that are carried long distances before settling to the bottom. Only a small volume of water is exposed temporarily to the harmful effects of the acids in the wake of the barge. No evidence was found that undesirable effects of any sort had been created by the disposal of the waste. There is a rapid exchange of coastal waters with the adjacent parts of the sea and, therefore, disposal of wastes in general in carefully selected areas in the sea is feasible without damage.

The survival of trout in KCN was studied. The survival period was affected by the size of the fish and the conditions under which they had been kept before the tests (47). One of the objects of the experiments was to develop bio-assay methods for the toxicity of industrial wastes.

Pulley (200) studied the effects of aluminum chloride on various marine organisms. In sea water, 44 p.p.m. of $AlCl_3$ did not kill adult fish, shrimp, or oysters; 88 p.p.m. killed young redfish quickly and other species more slowly; 132 p.p.m. killed all fish in a few days and most fish in a few hours; and 176 p.p.m. killed all fish in a few hours. Oysters are more resistant than fish.

Scheuring (210) found that sodium sulfate, a waste product of the staple-fiber industry, was not extremely toxic to water organisms, for various protozoa tolerated concentrations of 1.5 to 2.0 per cent for 28 days. Various species of water snails showed varying degrees of resistance, succumbing in 0.5 per cent within 7 to 28 days. Microcrustacea were very susceptible and died within 6 to 30 hr. The resistance of fish varied greatly; goldfish were relatively hardy, whereas trout fingerlings died in 0.5 per cent within 1 to 6 days. Growth of various water plants was temporarily stimulated in solutions of 0.5 to 1.0 per cent, but higher concentrations were detrimental. Green and blue-green algae flourished in concentrations up to 1.5 per cent.

Podubsky and Stedronsky (186) found that the toxicity of metals to pike fry and spawn manifested itself in the order copper, brass, and zinc. Iron was harmless. These authors (184) (185) also found that copper was most toxic to fish and river crabs, followed by zinc, brass, iron, and nickel. Aluminum was toxic in waters containing little calcium. Copper coated with zinc and tin, or iron coated with zinc, was slightly toxic, whereas stainless steel, or iron coated with nickel, chromium, or lead, was non-toxic. The effects of copper, brass, and zinc on plankton and insect larvae were studied. The slight concentration of these metals, which would not endanger fish, might destroy the zoo-plankton and some larger aquatic forms and would destroy fish habitats by the depletion of fish food organisms.

Ogi (177) treated artificially fertilized eggs of *Plecoglossus* with dilute solutions of lithium chloride and produced several types of monstrosities. Lithium was found to have deleterious effects on all types of body tissues. Lallier (143) found that immersing the eggs of amphibia in dilute solutions of lithium chloride slowed development and significantly reduced the oxygen consumption of the embryos.

Smith (218) found that fish lived in domestic tap water containing an average of 0.1 p.p.m. of copper.

LeClerc and Devlaminck (148) tested the toxicity to fish of various substances found in gas works wastes. The minimum amounts of the inorganic acids, bases, and their salts, as well as hemoglobin poisons and organics, causing death within 6 hr. were determined. The *in vivo* and *post mortem* symptoms caused by each substance were described. KCN was the most toxic of the substances examined. Chemicals used in oil well drilling were classified by Daugherty (91) into non-toxic substances, low-toxicity substances, and toxic materials. Caustic soda, oil well cement, Tannex, and white lime were fatal to many test animals in concentrations ranging from 70 to 450 p.p.m.

Wuhrmann and Woker (252) correlated concentration and reaction time in solutions of pure phenol for several fish species. The curve obtained follows a hyperbolic function and may be expressed by a linear relation. Jones (139) found that solutions of phenol, ortho- and para-cresol are highly toxic to fish and have an effect on the nervous system, causing them to lose their sense of balance and capability of coordinated movement. At low concentrations, minnows appear to have little discrimination between the toxicants and the water, and swim into the solution and become intoxicated. At higher concentrations, the fish will avoid the toxic solutions. Trahms (233) found that trout and perch died very quickly in a 0.16 per cent solution of phenol diluted with tap water. Carp could stand 1.9 per cent without injury. All dead fish had a bad smell and taste.

Sorenson (221) conducted experiments to determine the toxicity of an acid waste containing phenol as well as potassium, sodium, and iron. Daphnia were killed in 250 to 500 p.p.m. in 10 to 12 days, and in 750 p.p.m. in 4 days. These wastes were also toxic to algae.

In 1937, the life of Lake Orta was destroyed by cuprammonium (64). Only a few algae and rotifers survived. The situation has not improved in 20 years. No remedy is possible, as the pollution continues. Ammonia is high in the lake; nitrates are also high, with an atypical distribution. Chlorides are also abundant.

The wastes from sulfate pulping mills have organic compounds that are directly toxic to fish, according to von Essen (239). These are the resin acids present in the black liquor and the volatile components of the blow gases. Improved pulp washing techniques have resulted in the reduction of toxicities from black liquor losses. Halmi (118) maintains that pulping wastes harm streams by depleting the oxygen, resulting in the ultimate formation of $H_2S$ and methane. Experiments were conducted to determine the toxicity of alkaline effluents that had been treated in different ways. It was found that fertilized fish eggs were more resistant than newly hatched fry and these were more resistant than older developmental stages of the same species. When the sulfite effluent was treated with a sufficient amount of base, its poisonous effect was considerably reduced. Creating a foam of the sulfate effluents also appeared to be beneficial, as in this way the poisonous resins were almost entirely removed from the effluent. By mixing the effluents from sulfate and sulfite factories, their poisonous effects were so reduced that the eggs and fry lived as long in the undiluted effluent as in control waters. The experiments indicate that in this way means can be found to eliminate the harmful effects of pulping wastes.

Williams *et al.* (245) reported on a series of experiments made to determine the toxicity of sulfite waste liquors to four species of salmon. These tests were carried out in brackish water and demonstrated that some salmon species were more tolerant than others. Oxygen tensions in the test solutions were adequate and an actual toxicity was demonstrated. The authors believe that sulfur dioxide is responsible for part of the observed toxicity.

Trichloroethylene, which is used in cleaning and degreasing procedures, is toxic to fish and to the organisms responsible for the biological purification of sewage (65). A method of detection of trichloroethylene by the color formed with pyridine is described. Ganapati and Alikunhi (113) observed heavy mortalities among breeding fish caused by an alkaline waste water, which contained free chlorine, chlorides, and had a high content of suspended solids. Bio-assays with native fish indicated that the toxicity was due mainly to the free chlorine. *Gambusia* was able to survive in pond water containing 1 p.p.m. chlorine.

A comparison of the sensitivity of

bacteria and fish to toxic chemicals was made by Stone *et al.* (227). It was found that although fish and bacteria tolerate a similar range of pH values, fish are more sensitive than bacteria to most toxic substances.

Pyridylmercuric acetate, a slime control agent in paper mills which has been found to be a successful fish disease control agent, showed a specific toxicity to rainbow trout (110) (205) (207) (249). Toxicological observations by these authors revealed that pyridylmercuric acetate is non-toxic to brook trout, although it is toxic to rainbow trout in the same concentrations. A 5-p.p.m. concentration of this drug for 1 hr. was not toxic to rainbow fingerlings of less than 3-in. length, but was toxic to larger fingerlings of the same species. Observations indicate that fish losses increase with the rise in water temperatures and other changes in water conditions.

Lundgren (154) studied the distribution of phenylmercuric acetate, another slime control agent. Ninety per cent of the substance remained in the pulp and the mill effluent contained less than 0.01 p.p.m., the maximum tolerated by fish.

Young and Nicholson (256) reported extensive fish kills in streams tributary to the Tennessee River. Cotton boll weevil insecticides were washed with soils into the streams during a period of heavy rains and killed fish. These insecticides included toxaphene, gamma isomer of benzene hexachloride, DDT, and aldrin. Not only were fish killed, but also many species of fish food organisms were depleted. Warrick (243) stated that these fish kills were the first instance known to him in which extensive pollution of streams has resulted from the use of agricultural insecticides. The kills followed heavy rains and were associated with increases in the water levels of the streams and increased turbidity.

Muller (164) showed that 190 to 250 p.p.m. of Gesarol (DDT) was lethal to fish and fish food organisms. DDT dusts were less dangerous than emulsions or oil solution. Schwarz (212) studied the toxic effects of DDT and difluoro-diphenyl-trichlorethane to fish and frogs by examining the responses of the poisoned animals to electrical stimuli.

Daugherty and Garrett (93) determined the 24-hr. median tolerance limit ($TL_m$) for several substances discharged as wastes into ocean waters. Tests with *Lagodon rhomboides* gave the following 24-hr. $TL_m$; hydrocyanic acid, 0.069 p.p.m.; lactonitrile, 0.215 p.p.m.; acrylonitrile, 24.5 p.p.m.; 1, cyanobutadiene, 1,3, 71.5 p.p.m.; acetaldehyde, 70.0 p.p.m.

The toxicity of nicotine is evident in concentrations of 1:50,000 and 1:300,000 and is greater in alkaline than acid solutions (253). Fish can endure weak solutions for many days.

The number of salmon in Swedish streams has decreased greatly as a result of industrial pollution, dam erection, and overfishing (250). As a part of a major study, tests were made to determine the toxic effect on predatory fish of slaked lime, lysol, ammonia, derris root, arsenic, picrotoxin, and phenylmercuric acetate. In concentrations used, arsenic and picrotoxin had little effect. Ammonia in concentrations of 17 to 136 p.p.m. killed eels, roach, and trout in 15 to 16 minutes.

The Trent Fishery board (56) (234) investigated some major fish kills, several of which were due to preventable pollution. Many kills were due to the combined effect of high temperatures and low river flows during a prolonged drought. The river Derwent was polluted with sewage effluents and hot condensate from factories. The sudden release of large volumes of deoxygenated water by floods killed fish in downstream locations. Biological surveys showed that coal washing waters in the river Sence had affected adversely the flora and fauna of the upper river. The Dove river is affected adversely by water from a tributary contaminated by copper. In appendices, methods

are given for the biological detection of pollution.

The 1949 drought in Yorkshire (242) had so reduced the oxygen content of the rivers that slight amounts of pollution killed fish. Fish were killed when local thunderstorms caused flushing of gullies and surface drains and discharged storm waters from the sewers. The need for surveying and recording the water flow in slow-flowing rivers into which large volumes of sewage and industrial effluents are discharged is emphasized. Wagner (240) reported that the water level in many German streams was below average in 1949. Streams became heavily polluted with sewage and industrial wastes, causing fish kills. The connection between fish mortality, water flow, and types of pollution was analyzed. Of the kills, 27 per cent occurred in July.

Basu (67) reported on the ecology of fish ponds irrigated with sewage. Observations were made of the biological, chemical, and physical changes of these ponds after applications of varying amounts of sewage. After application of sewage the number of bacteria increased; this, in turn, was followed by an increase in the numbers of zooplankton. Phytoplankton increased on the third day after fertilization.

Mookerjee and Bhattacharya (162) investigated fish kills in two carp ponds. In one, algae excluded the light, dissolved oxygen was low, and hydrogen sulfide was present; fish of all ages died. In the other tank, *Microcystis* was present. At noon, during the height of photosynthetic activity, dissolved oxygen was high, the pH had increased to 9.55, and the young fish were killed. It was concluded that young fish cannot tolerate high alkalinity accompanied by a high concentration of organic matter, even when the content of dissolved oxygen is appreciably higher than normal.

LaRoze (145) described a case in which pollution of a river with tannery wastes caused fish kills because of oxygen depletion.

Spraying carp ponds with copper sulfate at a rate of 8 kg. per hectare per summer season has improved the carp production (76). Spraying has also proved successful in controlling gill rot, because it prevented mass formation of algae during warm weather and favored decomposition of dead water plants, thus augmenting plankton production.

Landa and Komers (144) maintain that refinery waste waters containing organic compounds kill fish by depleting the oxygen content. The purification of wastes containing phenols, naphthenic, and naphthenates and the toxic effect on fish of these substances, is described.

Schmassman (211) studied the toxicity to fish of synthetic detergents. Three products, one of unknown composition and two fatty acid concentration products, one containing pyridine, were tested with fish. In the product containing pyridine, the respiration and nervous system were affected. It appeared that both the fatty acid and the pyridine had adverse effects. Fish were killed in less than 12 hr. by 20 p.p.m. of the detergent of unknown composition.

Degens *et al.* (94) determined the time taken for different concentrations of several detergents to kill *Daphnia*, tadpoles, and various species of fish. In concentrations of 5 p.p.m. all detergents tested were lethal to the organisms within 10 to 100 hr., depending on the organism and the detergent. It was shown that, within limits, the animals could acclimate to 9 to 36 p.p.m. of the detergent. Water plants did not appear to be affected by the detergents in concentrations up to 40 p.p.m.

Cicutoxin (187), an extract from the water hemlock, is a virulent fish poison. It is easily extracted from *Cicuta* rootstalks and quickly penetrates into the fish. There is a possibility of poisoning young and delicate fish in small

shallow bays containing large quantities of cut-down *Cicuta*.

Fry (112) reviews the pertinent literature on the physiology and environmental relations of the trout. Acclimation and temperature selection and tolerance are discussed. It is shown that the reduction of the oxygen level to 50 per cent saturation would produce a very unsuitable environment, even at quite low water temperatures, to trout that had been acclimated to waters near saturation. Under ordinary circumstances, free carbon dioxide is not the first substance to exert an unfavorable effect on fish. In nature, speckled trout tolerate pH ranges from 4.1 to 8.5; in the laboratory, trout have been submitted to a pH of 3.3 to 10.7 without adverse effects. There is evidence that acclimation to various levels of pH takes place.

Basu (66) kept fingerlings of Indian fish in a continuous supply of water containing low concentrations of oxygen. The fish were able to survive for more than 24 hr. in concentrations of about 1 p.p.m., but in these low concentrations they remained very quiet, thus decreasing their need for oxygen.

Wallen (241) studied the effects of high turbidity on 16 species of fish. Observable behavioral reactions that appeared as turbidity effects did not develop until concentrations of turbidity approached 20,000 p.p.m. Most fish endured exposures to more than 100,000 p.p.m. for a week or longer, but these same fish finally died at a turbidity of 175,000 to 225,000. Turbidity is probably not a lethal condition to fish at turbidities found in nature.

Exposure of domestic animals and wildlife to atomic radiation is most likely to occur through contact with atomic wastes (126). The author reviews literature on effects of radiation to aquatic life and gives the radioactivity levels of streams receiving atomic wastes. Algae in the Columbia River have accumulated 1,000 times the level of radioactivity in the river waters. The highest observed internal radiation dosage of fish was about 80 per cent of the permissible daily exposure of plant personnel. There is not yet, however, evidence of pathological changes in aquatic organisms caused by radiation under natural conditions. General Electric Company (6), which operates the Hanford Works, is constructing an aquatic biology laboratory to determine the effect of effluent water from the piles on fish and fish food organisms in the Columbia, Yakima, and Snake Rivers.

Ross (206) reports cases of poisoning of men and animals at Fanning Island by fish which were formerly eaten with no ill effects. All fish were caught in areas where war materials had been dumped and it is suggested that the plankton on which fish feed contain a product from the deteriorating munitions. The toxic agent appears to produce symptoms similar to those of aconitine. Brunner (79) found that fish may carry pathogenic bacteria externally or internally. Bacteria on the skins of sharp-spined fish enter wounds on the hands of fish handlers, resulting in erysipelas. When fish ate food infected with Gartner bacteria or were kept in infected water, bacteria could be detected within a few days in the gut and later in the flesh. The author considers that the dangers of infection of fish are greatest where pollution of water by industrial wastes weakens the resistance of fish to bacteria, rather than where fish are grown in sewage works effluent.

The factors determining the growth and photosynthesis of phytoplankton under natural conditions are discussed and evaluated by Ketchum (142).

Tarzwell and Palmer (230) discuss the ecological, physical, and chemical conditions that affect the growth of the plankton that are of interest to users of water supplies. The increase of reservoirs as water supply sources has brought algae and actinomyceta nuisances to the attention of the ultimate consumer. The value of biologi-

cal studies to anticipate and alleviate nuisance conditions is emphasized.

Stundl (228) maintains that important clues regarding origin and pollution of waters can be obtained by microscopic examination of the suspended matter in the water. These may be composed of plankton and other matter.

The production of oxygen by algae in daylight, according to Stone and Abbot (225), generally exceeds the consumption of oxygen during the night. When a large proportion of sewage is present, the dissolved oxygen disappears completely during both daylight and darkness. Dilution of the sewage affects the length of time the algae-produced oxygen is present in the polluted water. The role played by microscopic green organisms in the purification of sewage is discussed by the same authors (226).

Flint (108) made a 3-yr. study of the algal flora of a London water resorvoir. During the early part of the study, the reservoir was in use and the water was changed constantly. Later, the inlet was closed and the water became stagnant, causing marked chemical and biological changes in the reservoir. At first, the plankton contained numerous *Chlorophyceae*, but a year later it consisted mainly of diatoms and *Myxophyceae*. Different planktonic and nonplanktonic algae were abundant at different periods of the year and it is suggested that their periodicity is related to variations in the intensity of the light and concentrations of various types of nitrogen, phosphorus, and silica. Lists of species commonly occurring under conditions of high and low concentrations of nitrogen, phosphate, and silica and with varying amounts of sunshine are given.

Ludwig *et al.* (152) find that algae in sewage convert nutrients into algal cell material, which when finally discharged to streams serves as a food supply for fish and other animals. The algae in effluents from sewage ponds are biologically active and can assist in the purification of watercourses. The algae convert nitrogenous substances to high-protein tissue, which may be of economic importance.

Osterlind (180) discusses physical and biological conditions that affect the growth of the alga *Scenedesmus*. Among subjects discussed are the assimilation of the carbonate ion, the influence of pH, growth rate determination at various pH values, comparison between nitrate and ammonia as sources of nitrogen, and the optimum and inhibiting effects of various $CO_2$ concentrations.

Studies were made of the ecology of the tropical inshore waters near Miami, Fla., by Smith *et al.* (217). Two of these stations were near the cities of Miami and Miami Beach, where the water was polluted with sewage and was rich in phosphates and nitrites. Many plankton were found at these and adjacent stations. Marine algae found in the Mediterranean near Alexandria, Egypt, were studied by Nasr and Aleem (172). The greatest numbers of algae were found in the spring, whereas the highest concentrations of the nutritive salts occur in the winter. Differing salinities at various stations determine algal species in these areas. The East Harbor of Alexandria receives sewage and has, therefore, a dense growth of certain algae. Bosshard (77) discussed the effect of hydrobiological changes on the operation of water treatment plants. The effects of seasons on the composition of the algal population and the effects of sewage on the bacterial number has been followed between 1909 and 1945.

Abbott (1) noted than an algal growth apeared after 1½ months in a closed bottle filled with settled sewage, despite the fact that much hydrogen sulfide was produced. The total sulfide was equivalent to 11.1 p.p.m. of sulfur. Fjerdingstad (106) found 124 species of plant microorganisms in stagnant ditches containing from 0.22 to 45.03 p.p.m. $H_2S$. The $H_2S$ is formed

by the decomposition of organic matter.

Flentje and Monie (107) and Monie (161) discuss algae in water supplies and the use of copper sulfate in algal control. Algae may cause objectionable tastes, odors, and color, and on disintegration are said to form toxic substances. The effect of temperature on the growth of several algal species is discussed and its importance in determining when it is necessary to apply copper is mentioned.

The disappearance of large areas of marine eelgrass during the past 50 yr. from European and American shores, causing a considerable depletion of fish and wildlife food, is discussed (55). Although the disease causing the disappearance of the eelgrass is associated with the fungus *Labrynthula,* it is possible that pollution from land and by oil from ships is a contributing factor. The toxic effect of oil on plants is discussed.

Louw (151) believes that several cases of poisoning of livestock in South Africa were caused by a blue-green alga (*Mycrocystis toxica*) growing abundantly in reservoirs. This alga can be controlled with copper sulfate. The methods used to isolate the toxin from the alga, as well as the effects of the toxin on small animals, are described. The toxin was found to be an alkaloid and was isolated as the picrate. Smit (216) described symptoms observed in small animals treated with the toxin and the changes seen on post mortem examination. Stewart *et al.* (224) report the loss of cattle in Ontaria due to poisoning by a species of *Microcystis* in the drinking water. The toxicity of the algae, symptoms, pathology, and the chemistry of algae poisoning are discussed. Growth of the alga was stimulated by continuous hot weather and the high contents of organic matter contributed by sewage pollution.

Wurtz (254) extracted the antibiotic from *Microcystis aeruginosa,* which has an antibacterial effect on *Clostridium bifermentans.* Filtered pure cultures of *Scenedesmus* have the same effect on *C. sporogenes.*

Daugherty (92) found oysters were killed in concentrations of sodium acid pyrophosphate in concentrations of 500 p.p.m. or greater. A decrease in irritability is evident for the first time at 400 p.p.m. and diminished progressively as the concentration of the salt increased.

Hoffman and Zakhary (128) found that temperature is a factor of primary importance in determining the effectiveness of copper sulfate when used as a molluscacide. Experiments over a range of 14° to 26° C. showed a 50-fold variation in toxicity, with the snails dying most rapidly at the higher temperatures.

Billib (74) traced many intestinal diseases in Northwest Germany to shrimps from Cuxhaven. The shrimps are obtained from mudbanks in the estuary of the Elbe, which are polluted by sewage from Cuxhaven and by waste waters from fish handling and processing plants.

Rudy (208) believes that the decrease in the fish population of the Staffelsee, Bavaria, is due indirectly to the clearing of a large woody area south of the lake. Acid water now drains from this area to the lake, destroying aquatic plants and causing the disappearance of clams. The author emphasizes the harmful effects on ground water, plant growth, and fisheries of the acidification of soil caused by extensive planting of pines and draining of swamps.

Cercos (83) found that the toxic effect of fungocin, a detergent antibiotic of protein nature, on the fish *Gambusia affinis* follows a regular curve up to a dose of 500 $\mu$g. per ml. Fungocin is also toxic to tadpoles. Bacilomycin has a toxic effect on fish.

## Chemistry

It was reported by Patterson (182) that the Carney River in Oklahoma has suffered increased pollution by oil

brines until it contains more than 200 p.p.m. of chloride and has a salty bitter taste. Textile wastes, according to Murdock (168), are objectionable in streams because of their color, sulfite, and metallic salt content, resulting in highly colored alkaline waters for several miles downstream below their discharge. Churchill (84) pointed out that paper and pulp mill wastes rendered many miles of otherwise clean streams dark and objectionable in color. It required 40 c.f.s. per ton of paperboard produced, plus considerable natural purification, to reduce the color to that considered normal for streams in the area.

Phenol concentrations should not exceed 2 p.p.b. after initial dilution in streams for protection against tastes in water supplies according to DeLaporte (95). This limit in streams would require treatment of effluents to reduce phenol content to 20 p.p.b. before discharge. Ettinger *et al.* (103) studied the persistence of phenols and cresols in polluted waters under anaerobic conditions and reported removals of 1 p.p.m. of phenol and orthocresol at room temperature after 14 and 7 days, respectively. At 4° C. the same quantity of these phenolics required 33 and 9 days, respectively, for removal anaerobically. Serial additions indicated acclimatization with more rapid removal, but atypical runs were also reported in which the phenol was not completely used up. According to Ettinger and Ruchhoft (104), phenolic materials in polluted water fall into three groups as determined by the results of stepwise partial chlorination: (a) phenolic materials which have their taste-producing intensity enormously increased (phenol, the cresols, and o-chlorophenol); (b) phenolic materials which have their taste intensity progressively decreased (1-naphthol, and 2,4-dichlorophenol); and (c) phenolic materials of limited intensity (4-chlorophenol and all of the phenols studied which had three or more positions chlorine substituted). Bulicek (80) reported that phenolic wastes contribute a large part of the stream pollution problem caused by industrial wastes in Czechoslovakia.

The effect of cyanide on the B.O.D. reaction in polluted waters was found to be quite variable by Ludzack *et al.* (153). Special microbic growths were able to oxidize organic matter in the presence of cyanide after an initial lag period. Little reduction of cyanide was accomplished during a normal 5-day incubation; in river waters there was a proportionally greater effect of small doses of cyanide on the inhibition of B.O.D. As much as 50 per cent or more of the organic matter as in the control was stabilized at 20° C. in the presence of cyanide concentrations up to 6 p.p.m. within a 10-day incubation period. Skopintsev (214) followed the biological oxidation in river waters over a period of 180 days at 16° to 20° C. He found the reaction unimolecular, with a reaction constant of 0.01 to 0.06. He concluded that incubation periods of 5 to 10 days give only relative values on the oxidation of unstable compounds and that incubation periods of 50 days or more are required. Albright (3) reports that oxygen (as sodium nitrate) equivalent to 10 to 20 per cent of the 5-day B.O.D. reduces offensive odors in a badly polluted stream. Murdock (165) discusses the control of $H_2S$ odors in the Androscoggin River by the addition of sodium nitrate on the basis of the water temperature, sulfite liquor load, dissolved oxygen, and methylene-blue stability. During 44 days, 641.5 tons of sodium nitrate were used to reduce the $H_2S$ to 0.01 p.p.m.

Jepson and Greene (138) showed experimentally that nitrates were not reduced until D.O. totally disappeared, and confirmed the generally accepted view that the presence of nitrates delays or prevents the onset of nitrification.

The concentration and estimation of organic chemical compounds in the Ohio River (78) was 9.3 to 32 p.p.b. using a carbon filter extraction tech-

nique, with lowest concentration detected by the threshold odor test ranging from 3 to 25 p.p.b. The quantitative extracts reported might be subject to considerable error, due to deficiencies in the carbon used, in variation in filtration rates, and metering errors. The technique seems promising for special stream and industrial waste studies.

### B.O.D. and Oxygen Sag

Lee (149) discussed the mathematical analysis of B.O.D. data. He believes the 20° C. $k$ is usually 0.1 and attributes most of the other values reported to "failing to recognize the effect of the initial demand for oxygen." Williams (246) reported that bottle experiments yielded a mean 20° C. $k$ value of Minneapolis–St. Paul plant effluents of 0.192, with 0.162 the mean $k$ for the raw influent. On samples of the Mississippi River, which receives the plant effluent, lower $k$ values were observed, the values decreasing with increased dilution, and also showing decrease as the receiving stream had a chance to recover from new pollution. Murdock (166) commented on the progress of studies by the National Council for Stream Improvement aimed at stream improvement through suplying air to receiving waters to permit the stream to more quickly recover from its pollutional load, and also summarized (169) the effect of low stream temperatures in retarding self purification. Bollens (75) discussed the relationship between microbiological metabolism and the satisfaction of B.O.D.

### Stream Standards

The New York State Water Pollution Board adopted standards of water quality for seven classes of surface water based on the best usage of waters (174). Similarly, standards of water quality for ground water and tidal water were adopted. The standards vary from Class AA waters, which are not polluted and may require only disinfection for best usage as drinking water, through different degrees of pollution and best usage to Class F, for which the best usage is sewage or industrial wastes disposal and the standard of water quality is such as to prevent a public nuisance. Intermediate classes consider the suitability of the water for sources of drinking water, bathing, fishing, agricultural uses, industrial uses, etc.

The fresh-water "standards" have been condensed and tabulated by Hess (123) for ease of comparison. The principal features of the standards, according to Hess, are: (a) disposal of wastes is one recognized best usage for waters in New York State; (b) any class of waters can be used for purposes listed in all lower classes, provided the specifications of that class are not violated; (c) no numerical limits are given for a large proportion of the specifications; (d) the limits for phenol compounds are related to water use for drinking and food preparation, rather than effects on fish life; (e) the limit for dissolved oxygen in Class D is related to fish survival, rather than to industrial or agricultural usages; and (f) the system indicates toxic, deleterious, colored, or other wastes, or heated liquids may be limited in Classes A to D by best usage other than those specified. In discussing the similarity of the New York standard for Class A with the International Joint Commission objectives, it is pointed out that the New York standards are limited to receiving waters, whereas the objectives include both effluent and receiving waters.

The application of the Pennsylvania standards for control of pollution in Class A, B, and C streams was discussed by Daniels (89). The standards of effluent quality discharging into a stream are based on "percentage removal" required for the treatment of domestic sewage. The treatment required of an industrial waste is interpreted as that treatment necessary to produce an effluent comparable to that required for domestic sewage

treatment. This eliminates the need of extensive studies on each industrial waste. The objectives of boundary water quality of the International Joint Commission were given and discussed by Berry (70). The objectives of adequate control of pollution include both treatment plant effluent and surface-water quality.

### Stream Surveys and Studies

The Ohio River Valley Water Sanitation Commission (178) reviews in detail its activities, projects undertaken, progress made in pollution abatement, and pollution abatement objectives. The final report of an extensive water quality survey of the Ohio River (179) involved a 12-day program of simultaneous sampling at 36 sampling stations located along a 963-mi. stretch of the river. Hydrometric data and the results of bacteriological, sanitary, chemical, and mineral determinations are presented in detail.

An intensive survey of a 130-mi. stretch of the Wabash River (Indiana-Illinois), sponsored by the Ohio River Valley Water Sanitation Commission (24), was accomplished through the combined efforts of eight cooperating organizations. More than 1,000 samples were collected in the 25-day sampling program. Results of the survey permitted determination of the requirements for waste treatment facilities at Terre Haute and Vincennes, Ind.

The Public Health Service released a report on a comprehensive water pollution survey of the South Platte River basin (198) (Colorado, Nebraska, Wyoming) produced in cooperation with the Bureau of Reclamation, the Colorado State Department of Public Health, and the City and County of Denver, Colorado, which includes a description of the basin, discusses its economic development, uses of water resources, pollution damages to water resources, benefits which may accrue as a result of pollution abatement, pollution prevention measures in effect, pollution abatement needs, and recommendations relative to water pollution control programs.

A water pollution survey of the St. Johns River at Jacksonville, Fla., is described by Sheddon (213). He concludes that pollution makes the stream unsatisfactory for bathing, but that it does not prevent the use of the stream as a source for domestic water supply and does not present a problem concerning fish and wildlife conservation or shellfish culture. A summary of information concerning water quality, stream flows, and sources of pollution for each of Florida's major rivers, is presented by Phelps and Barry (183). Special reference has been given to the statistical probability of low stream flows of specified magnitude.

A 3-yr. study to determine the limitations on the ability of Baltimore Harbor to accept waste discharges without undergoing objectionable changes is reviewed by Garland (114). The study included hydrographic investigations, investigation of sources and types of waste loadings, and chemical and bacteriological water quality determinations. A study of the shore waters of Biarritz, France, is reported by Souchard, Andrieu, and Darmendrail (222). Sea currents and dilution prevent the contamination of nearby beaches, but the authors conclude that the major purifying action is from the antibiotic power of sea water.

A survey of Port Gardner Bay and the Snohomish River estuary, made during the fall of 1949 is reported by Eldridge and Orlob (102). A pollutional barrier caused by waste discharged by two sulfite pulp mills and Everett, Wash., has been demonstrated to exist in the estuary of the south branch of the river. Fish kills have occurred and river frontage and beach areas have been adversely affected by the pollution.

Ketchum (141) presents a method of calculating the effective dilution of fresh water flowing into an estuary and a means of determining the ratio of

fresh to salt water at any location in the estuary if the physical characteristics of the latter, the rate of river flow, and the position of the tides are known. The results of the study represent a refinement over the tidal prism method for the analysis of dilution problems in tidal estuaries.

A biodynamic study of the Conestoga River, Pa. (181), to determine if organisms living in a stream could serve as indices of stream conditions, particularly as related to domestic and industrial wastes pollution, indicates that a great many species, none represented by a great number of individuals, will be present in a healthy stream, but that pollution will eliminate less tolerant species and permit greater abundance of the more resistant ones. A brief description of a biodynamic stream survey of this type, made prior to the construction of a nylon intermediates plant by the du Pont Company, is given by Murdock (169).

Dougan and Bell (101) discuss the manufacturing processes of a synthetic rubber plant and describe its waste materials and methods of waste treatment. The study included a survey of a 20-mi. stretch of the stream which receives the plant's effluent. Bergamin and Correa (69) describe the condition of a small stream which receives the wastes of a tannery, five textile works, and the sewage of a town.

The report of the International Joint Commission studies of 1946–1948 on the pollution of boundary waters has been released (135). A survey of industrial wastes in the Lake Huron-Lake Erie section of the boundary waters from the International Joint Commission studies is presented by Berry, Black, and Oeming (73). Discussion of the industrial wastes program is comprehensive and the progress which has been made in pollution control is reported. Two other articles dealing with the International Joint Commission study of the pollution of boundary waters presented by Berry (71)(72), include discussions of both domestic and industrial wastes.

A water quality survey of Lake Erie by the Division of Water, Ohio Department of Natural Resources, has been reported (30). Highly polluted tributary streams appear to be the worst offenders in the pollution of the lake. Determinations of coliform organisms, B.O.D., and dissolved solids were included in the survey. A majority of the bathing beaches sampled were found to be polluted beyond tolerated public health limits. Dewitt and White (98) presented a preliminary report on the characteristics of pollution of large, relatively still bodies of water by the entrance of contaminated tributary streams.

The results of determinations of discharge, temperature, color, dissolved and suspended solids, and selected mineral and chemical constituents of the waters of many surface streams in the United States, have been published (236). Data for the publication were collected during the period October, 1945, to September, 1946. Additional information concerning oxygen consumed values, pH, and concentrations of additional chemical constituents, is given for a number of the streams.

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The Hotel Statler at New York City will be the headquarters for the Federation's Twenty-Fifth Annual Meeting, to be held in October. An outstanding Silver Anniversary program is being planned for the four-day meeting.

Requests for room reservations should be addressed directly to the hotel. It should be noted that the technical program will open on Monday morning, October 6, and will close at noon on Thursday, October 9. However, the usual inspection trip will this year be scheduled for the afternoon of October 9, after the close of the meeting.

**WRITE NOW FOR YOUR RESERVATIONS!**

# Sewage Works

## HETEROTROPHIC BACTERIA ENCOUNTERED IN INTERMITTENT SAND FILTRATION OF SEWAGE *

By W. T. Calaway, W. R. Carroll, and S. K. Long

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A considerable amount of research has been done in the past upon the principal bacteria found in various types of sewage purification processes (for example, activated sludge and trickling filters), but there has been a noticeable lack of bacteriological work, in modern times, on sand filters. It is obviously as important from a scientific viewpoint to know the bacteriological "why's and wherefore's" of sand filtration as it is to be familiar with those for the other mentioned processes. The value of determining the more important species of bacteria present in the filter, and some indications of their physiological properties in the decomposition of the organic constituents of sewage, is readily apparent.

The work here reported is a part of a project entitled "Microbiology and Ecology of Sewage Filtration Through Sand," which is sponsored by the National Institutes of Health † upon the recommendation of the Environmental Health Study Section. This project is a study of basic biological, chemical, and physical interrelationships, the objective of which is to advance the fundamental knowledge of sewage treatment in general and of intermittent sand filtration specifically.

The first demonstration of the part that atmospheric oxygen plays in the purification of sewage was made by Frankland in 1868; however, he erred in assuming that the organic matter in sewage was directly oxidized as it dripped through the filter. The research and development period of filtration actually began with the establishment of the Lawrence Experiment Station in Lawrence, Mass., in 1887; it is from this source that a majority of the early material on filtration was obtained. The first mention of the importance of biological action in sand filtration was made by Sedgwick (15), who stated that the organisms necessary for purification soon establish themselves in the filter and are directly concerned with destruction of the organic constituents. Clark and Gage (5)(6)(7)(8)(9), in their excellent papers on filtration at Lawrence, present many interesting discussions on the importance and functions of various bacteria in filters. Hotchkiss (12), from studies on trickling filters, concluded that proteolytic bacteria predominated in the filter and that bacteria concerned with nitrogen transformations were abundant. Gaub (10), Levine and Watkins (13), and Bollen (1) identified numerous genera and species from trickling filters and polluted waters. Butterfield (3) made the first detailed bacteriological study upon ac-

* A contribution of the Sanitary Research Laboratory of the University of Florida.

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tivated sludge. He concluded that *Zooglea ramigera* was the principal organism concerned with this type of purification. Whitehead and O'Shaughnessy (18) and Wattie (17) also made studies on activated sludge using Butterfield's (3) techniques.

The following study was made on a sand filter 1/800 of an acre in area. The sand of this filter has an effective size of 0.31 mm. and a uniformity coefficient of 3.3. The filter was being regularly dosed with slightly weak sewage, which varies in strength from 60 to 120 p.p.m. B.O.D., with an average strength of about 100 p.p.m. of 5-day B.O.D.

## Methods

### *Sampling for All Bacteriological Work*

Samples were taken from the filter in the following manner:

1. Surface sand samples.—A small section of the dried crust on the surface of the filter was removed with a flamed spatula and discarded. A portion of the exposed sand was removed and placed in a clean beaker and covered with a petri dish lid.

2. A special coring device was used for taking samples from the 6-in., 12-in., 18-in., 24-in., and 30-in. levels. This device was constructed of 2-in. diameter steel pipe with one end ground to a sharp edge to facilitate penetration of the sand. The pipe was scored at 6-in. intervals to permit rapid determination of the depth attained.

Samples were obtained by driving the pipe into the bed to the desired depth and withdrawing carefully. Portions of the sand retained were removed from the center of the sand in the end of the tube and placed in clean beakers, covered, and labeled. For individual samples within the bed, coring was done at widely separated locations.

### *Processing of Samples*

1. General aerobic heterotrophic bacteria.—This group includes all organisms which grew well under aerobic conditions and on standard nutrient agar. Only the most numerous types of these organisms present in the filter were studied, efforts being directed toward identification of only the predominant bacteria.

Portions of each sample containing 10 g. ± 0.1 g. were weighed out and placed in sterile 100-ml. water blanks. These blanks were shaken vigorously for 3 min. to suspend the bacteria, and then were allowed to stand for 3 min. to permit the sand to settle. This mixture was considered to be a 1:10 dilution (10 g. sand per 100 ml. water). Serial dilutions were then made to the required degree. (Two to four days previous to each series of samples, test plate counts were made for each level of sand to aid in determining the proper dilution.) After the dilutions were made, a 1-ml. portion of each sample was plated out using nutrient agar and the pour plate method. Dilutions between 1:1,000,000,000 and 1:10,000 were required for the surface level, and 1:1,000,000 to 1:10,000 for the lowest levels, with the other levels ranging between these figures. All plates were incubated at 25° to 28° C. for 7 days. At least three colonies representing the more numerous types were picked and transferred to nutrient agar slants. Total plate counts and counts of the colonies picked were made and recorded.

All cultures were purified using the loop dilution technique. These cultures were then identified by comparing their characteristics with those found in "Bergey's Manual of Determinative Bacteriology" (2).

2. Enumeration of zooglea-forming bacteria.—Sampling for this portion of the study was done in the same manner as that for the general heterotrophic bacteria. Because of the problems involved in estimating numbers of zoogleal bacteria, these samples required special handling. A technique for this purpose was developed which was based on Butterfield's (3) studies

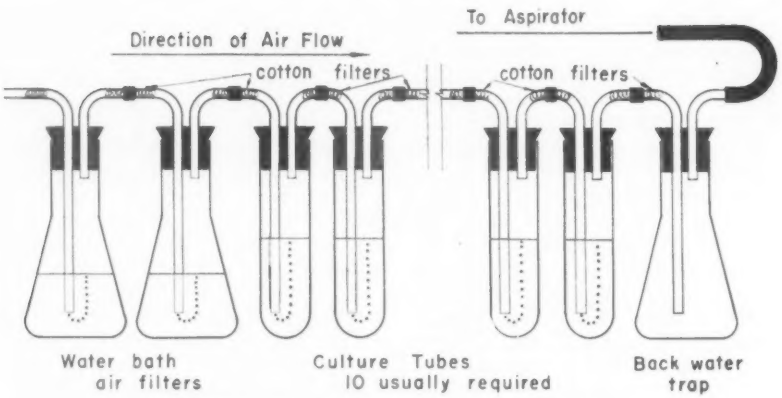


**FIGURE 1.—Aerating apparatus for bacterial cultures.**

in which he found that an unfavorable environment caused dispersion of the bacteria from the gelatinous matrix or floc, and that this phenomenon could be prevented by adding approximately one part of nutrient broth to nine parts of the water used.

The zoogleal films were washed from the samples of sand using sterile broth-water mixtures and shaken vigorously for 5 min. The samples were then allowed to stand just long enough to permit the sand to settle out. The supernatant from each washed sample was removed and placed in sterile, stoppered centrifuge tubes. These films were washed with sterile broth-water mixtures using low-speed short-time centrifugations at least 14 times. The material remaining was then removed and placed in a 100-ml. sterile-water blank containing no added nutrients. This was considered to be a 1:10 dilution (zooglea content of 10 g. of sand in 100 ml. of water). The unfavorable conditions caused by the plain distilled water created conditions sufficiently unfavorable to cause dispersion of the bacteria from the flocs. The dispersed bacteria were then serially diluted and a 1-ml. portion of each dilution was removed and placed in the special aerating apparatus (Figure 1) containing sterile sewage. These tubes were vigorously aerated for seven days, fresh sterile sewage being added every 24 hr. to maintain a high concentration of nutrient materials.

All tubes showing floc formation at this time were removed from the apparatus and allowed to stand for 15 min. The supernatants were then discarded and portions of the floc-like material remaining were removed. Microscopic examinations were made on unstained flocs, flagella stained flocs (Gray's method) (16), and flocs stained with capsule stain (Anthony's) (16).

3. Miscellaneous studies.—(a) In addition to the two foregoing studies, determinations were made on the numbers and distribution of coliform organisms and fecal streptococci within the sand at various levels of the filter, in the applied primary sewage, and in the filter effluent. Examinations for these organisms were made on the primary and final effluents and upon the surface, 6-in., 12-in., 18-in., and 24-in. levels of sand. In the case of the fecal streptococci, determinations were also made on the 30-in. level of sand. All samples, with the exception of those from the effluents, were treated exactly as outlined for the general heterotrophic bacteria.

The medium used for most probable

**TABLE I.—Characteristics of General Heterotrophic Bacteria Found in Intermittent Sand Filters**

| Depth (in.) | Genus and Species | Shape | Gram Stain | Spores | Chromogenesis | Gelatin | Nitrates | Lactose | Sucrose | Glucose | Maltose | Mannitol | Indole | $H_2S$ | Nitrates | $NH_4H_2PO_4$ | Litmus Milk |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | *Fl. aquatile* | Rod | − | None | Yellow | L | NR | NC | NC | NC | NC | NC | — | — | NU | NU | NC |
| | *B. pumilus* | Rod | + | Present | None | L | NR | NC | A | A | NC | A | — | — | NU | NU | NC |
| | *Al. faecalis* | Rod | − | None | None | NC | R | NC | NC | NC | NC | NC | — | — | U | NU | P |
| | *B. alvei* | Rod | + | Present | None | L | R | NC | A | A | A | NC | — | — | NU | NU | PR |
| | *Fl. balustinum* | Rod | − | None | Ochre | L | NR | NC | NC | A | A | ND | — | — | NU | NU | PR |
| | *Streptomyces* sp. | ND | ND | Present | None | NC | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | P |
| | *Nocardia* sp. | Pleomorph | + | None | Pink | NC | R | NC | NC | NC | NC | NC | — | — | U | U | PR |
| | *B. cereus* | Rod | + | Present | None | L | R | NC | NC | A | A | NC | — | — | NU | NU | PR |
| 6 | *B. megatherium* | Rod | + | Present | None | L | NR | NC | A | A | A | NC | — | — | NU | U | NC |
| | *Fl. devorans* | Rod | − | None | Yellow | L | NR | NC | NC | NC | NC | NC | — | — | U | NU | NC |
| | *Fl. aquatile* | Rod | − | None | Yellow | L | NR | NC | NC | NC | NC | NC | — | — | NU | NU | NC |
| | *Al. bookeri* | Rod | − | None | None | L | NR | NC | NC | NC | NC | NC | — | — | NU | NU | PRC |
| | *Streptomyces* sp. | ND | ND | Present | None | NC | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | P |
| | *B. cereus* | Rod | + | Present | None | L | R | NC | NC | A | A | NC | — | — | NU | NU | PR |
| | *B. alvei* | Rod | + | Present | None | L | R | A | A | A | A | A | — | — | NU | U | AP |
| | *Nocardia* sp. | Rod | − | None | Yellow | L | NR | NC | NC | NC | NC | NC | — | — | NU | NU | P |
| | *B. subtilis* | Rod | + | Present | None | L | R | NC | A | A | A | A | — | — | U | U | PR |
| | *Nocardia* sp. | Pelomorph | + | None | Pink | NC | R | NC | NC | NC | NC | NC | — | — | U | U | PR |
| | *Fl. balustinum* | Rod | − | None | Ochre | L | NR | NC | NC | A | A | ND | — | — | NU | NU | PR |
| 12 | *Fl. aquatile* | Rod | − | None | Yellow | L | NR | NC | NC | NC | NC | NC | — | — | NU | U | NC |
| | *B. alvei* | Rod | + | Present | None | L | NR | NC | A | A | A | A | — | — | NU | U | PR |
| | *Streptomyces* sp. | ND | ND | Present | None | NC | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | P |
| | *B. cereus* | Rod | + | Present | None | L | R | A | A | A | A | NC | — | — | NU | NU | PR |
| | *Nocardia* sp. | Pleomorph | + | None | Pink | NC | R | NC | NC | NC | NC | NC | — | — | U | U | PR |
| | *B. circulans* | Rod | + | Present | None | L | R | NC | NC | A | A | NC | — | — | NU | NU | PR |
| 18 | *Fl. aquatile* | Rod | − | None | Yellow | L | NR | NC | NC | NC | NC | NC | — | — | U | U | NC |
| | *Al. bookeri* | Rod | − | None | None | L | NR | NC | NC | NC | NC | NC | — | — | NU | NU | PRC |
| | *B. cereus* | Rod | + | Present | None | L | R | A | A | A | A | NC | — | — | NU | NU | PR |
| | *B. alvei* | Rod | + | Present | None | L | NR | NC | A | A | NC | A | — | — | NU | U | A |
| | *Nocardia* sp. | Pleomorph | + | None | Pink | NC | R | NC | NC | NC | NC | NC | — | — | U | U | PR |
| 24 | *Al. bookeri* | Rod | − | None | None | L | NR | NC | NC | NC | NC | NC | — | — | NU | NU | PRC |
| | *Streptomyces* sp. | ND | ND | Present | None | NC | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | P |
| | *B. cereus* | Rod | + | Present | None | L | R | A | A | A | A | NC | — | — | NU | NU | PR |
| | *Nocardia* sp. | Pleomorph | + | None | Pink | NC | R | NC | NC | NC | NC | NC | — | — | U | U | PR |
| | *B. alvei* | Rod | + | Present | None | L | R | NC | A | A | A | ND | — | — | NU | NU | PR |
| 30 | *B. cereus* | Rod | + | Present | None | L | R | NC | NC | A | A | NC | — | — | NU | NU | PR |

Key

L = liquefaction
R = reduced
NR = not reduced
NU = not utilized
U = utilized

A = acid
P = peptomized
C = coagulated
NC = no change
AG = acid and gas
\+ = positive
− = negative
ND = not determined

Generic abbreviations
Fl. = Flavobacterium
B. = Bacillus
Al. = Alcaligenes

numbers of coliforms was standard lactose broth, with the criterion for positive tubes being gas production in 24 hr. A special selective medium was required for the determination of the number of fecal streptococci. It was found that Rothe's dextrose azide broth (14) was excellent for this purpose. The appearance of growth in tubes of this medium in 48 hr. constituted a positive reaction. Stained smears made from positive tubes showed macroscopic examination of the tubes to be 90 per cent accurate.

The numbers of both types of organisms were determined according to Hoskins' (11) tables for most probable numbers. Several series of tests were made for each type of determination and the geometric means of coliform organisms and fecal streptococci were computed for the effluents and each level of sand. Some isolations were made from positive tubes from each of the two above studies, and after being purified, the cultures were identified by reference to "Bergey's Manual" (2).

(b) Because many of the organisms in the group of general heterotrophic bacteria are often found in soil, which is the most important source of antibiotic-producers, it was of interest to determine whether these organisms are capable of antibiotic-production in the filter. The relation, if any, between antibiosis and decrease in number of enteric organisms in the filter was investigated. A representative number of cultures was tested against various enteric pathogens, coliform organisms, and one species of Gram-positive coccus.

## Results

### *General Heterotrophic Bacteria*

It was found that the highest total plate counts, and counts for identified heterotrophic organisms, were obtained in the first two plating series, which were made during the months of November and December. Air temperatures at this time ranged from 10° to 24° C. during the daytime and 5° to 9° C. at night. The rate of dosing at this time was 300,000 g.p.a.d. (gallons per acre per day).

In January, due to overloading and the low temperatures prevailing, it was necessary to rest the filter for three weeks. When dosing was resumed, the rate was reduced to 150,000 g.p.a.d.

**TABLE II.—Summary of Distribution of Predominant Species in Intermittent Sand Filters and Variations in Plate Counts**

| Depth (in.) | Genus[1] and Species | Plate Counts[2] | |
|---|---|---|---|
| | | Minimum | Maximum |
| 0 | *Fl. aquatile* | 2.5 | 300,000 |
| | *B. pumilus* | 90 | 80,000 |
| | *Al. faecalis* | 1.0 | 1,000 |
| | *B. alvei* | 1.0 | 140 |
| | *Fl. balustinum* | 1.0 | 10 |
| | *Streptomyces* sp. | 10 | 10 |
| | *Nocardia* sp. (1) | 5.0 | 5.0 |
| | *B. cereus* | 0.5 | 5.0 |
| 6 | *B. megatherium* | 300 | 300,000 |
| | *Fl. devorans* | 300 | 200,000 |
| | *Fl. aquatile* | 2.0 | 150,000 |
| | *Al. bookeri* | 60,000 | 60,000 |
| | *Streptomyces* sp. | 300 | 1,500 |
| | *B. cereus* | 1.0 | 200 |
| | *B. alvei* | 1.0 | 100 |
| | *Nocardia* sp. (2) | 0.5 | 10 |
| | *B. subtilis* | 0.5 | 5.0 |
| | *Nocardia* sp. (1) | 1.0 | 1.0 |
| | *Fl. balustinum* | 0.1 | 0.1 |
| 12 | *Fl. aquatile* | 10 | 30 |
| | *B. alvei* | 1.5 | 20 |
| | *Streptomyces* sp. | 10 | 10 |
| | *B. cereus* | 1.0 | 10 |
| | *Nocardia* sp. (1) | 1.0 | 1.0 |
| | *B. circulans* | 0.5 | 0.5 |
| 18 | *Fl. aquatile* | 20 | 20 |
| | *Al. bookeri* | 10 | 10 |
| | *B. cereus* | 1.0 | 3.0 |
| | *B. alvei* | 0.3 | 2.0 |
| | *Nocardia* sp. (1) | 0.3 | 0.3 |
| 24 | *Al. bookeri* | 20 | 20 |
| | *Streptomyces* sp. | 10 | 10 |
| | *B. cereus* | 0.3 | 1.0 |
| | *Nocardia* sp. (1) | 0.2 | 0.2 |
| | *B. alvei* | 0.2 | 0.2 |
| 30 | *B. cereus* | 0.15 | 0.15 |

[1] For generic abbreviations see Table I.
[2] Expressed as millions per gram of sand.

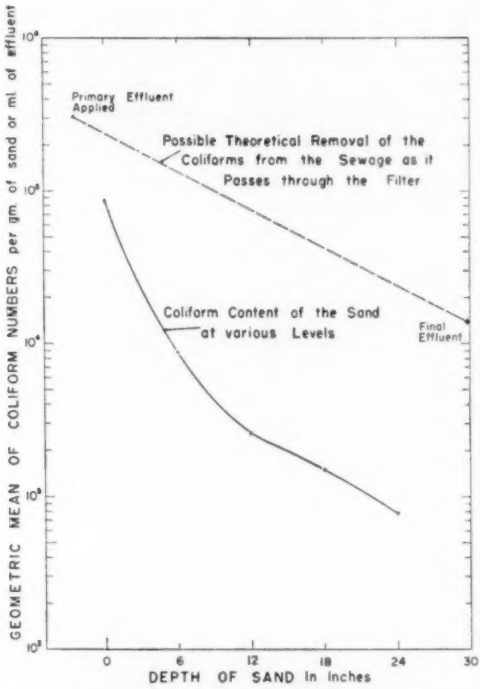
GEOMETRIC MEAN OF COLIFORM NUMBERS per gm of sand or ml of effluent
Primary Effluent Applied
Possible Theoretical Removal of the Coliforms from the Sewage as it Passes through the Filter
Coliform Content of the Sand at various Levels
Final Effluent
0
6
12
18
24
30
DEPTH OF SAND in inches

**FIGURE 2.—Distribution of coliform bacteria in intermittent sand filter.**

With the lower dosing rate, a noticeable decrease was obtained in plate counts at all levels; these counts, however, were extremely variable.

Fourteen species comprising five genera were identified from various levels of the filter. Table I indicates their reactions on differential media. The organisms are arranged according to the level from which they were isolated and in order of decreasing counts (see Table II).

*Zoogleal Bacteria*

It was found, on the basis of several series of tests, that the gelatinous masses or floes produced by these bacteria were always readily formed at dilutions of 1:10,000,000,000 and 1:100,000,000,000 for the surface and 6-in. levels of sand. No visible floc formations were ever obtained at dilutions of 1:1,000,000,000,000 for either level. Flocculent growth was formed in dilutions of 1:10,000,000 and 1:100,000,000 of the 12-in. level of sand. A dilution of 1:100,000,000 was consistently the highest dilution showing floc formation in this level. There was never any floc formation in samples from the 18-in. and 24-in. levels in dilutions as low as 1:1,000,000.

Referring to the foregoing data, it may be assumed that the minimum count of zoogleal bacteria at the surface and 6-in. levels was 100,000,000,000 per gram of sand, and for the 12-in. level, 100,000,000 per gram of sand. It should be noted that these counts may only be considered to be the minimum counts, due to incomplete removal of the zoogleal films from the sand, incomplete dispersion of the bacteria from the zoogleal matrix, and perhaps

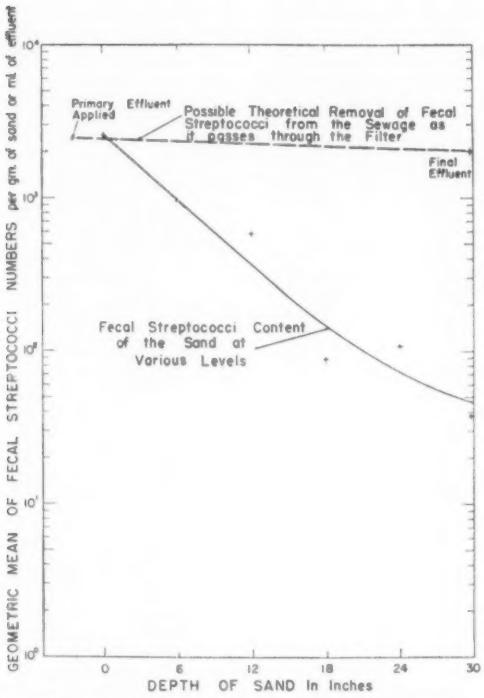
GEOMETRIC MEAN OF FECAL STREPTOCOCCI NUMBERS per gm. of sand or ml. of effluent
Primary Effluent Applied
Possible Theoretical Removal of Fecal Streptococci from the Sewage as it passes through the Filter
Final Effluent
Fecal Streptococci Content of the Sand at Various Levels
DEPTH OF SAND In Inches
0
6
12
18
24
30

**FIGURE 3.—Distribution of fecal streptococci in intermittent sand filter.**

some loss of the bacteria during washing.

Flagella stains of the dispersed flocs showed the presence of medium rods of a noticeable uniformity in size: 1.5 by 2.0 to 2.3 microns, with monotrichous, lophotrichous, and peritrichous flagellation. Lophotrichous flagellation was most often found. The flagella varied in length from 1 to 3 microns, regardless of type. Capsule stains of the undispersed flocs revealed the presence of medium rods within the flocculant matrix.

*Miscellaneous Studies*

The decrease in numbers of coliform organisms was found to be continuous throughout the filter, with the greatest number occurring in the surface level of sand. Approximately 95 per cent of the coliform organisms present in the primary effluent were removed by passage through the filter. The fecal streptococci also exhibited a decrease from primary to final effluent, although not as marked as the coliforms. Coliform organisms and fecal streptococci were present in all levels of sand, in the primary sewage applied, and in the final effluents.

There is a possibility that, on the basis of more tests, the curves of decrease of coliforms and fecal streptococci (Figures 2 and 3) could be resolved into straight lines, from which the mean concentration of either type of organism for any given depth of sand might be calculated. It would appear that there should be some relationship between this mean concentration and the total removal of these organisms by the filter, but with the

data available at present no such relationship is apparent.

*Aerobacter aerogenes* and *Streptococcus faecalis* were isolated from positive tubes of the coliform and fecal streptococcus tests, respectively. Although no other coliform organisms were isolated, it cannot be assumed that they were not present.

As a point of interest, although perhaps of slight importance, many of the lactose broth tubes exhibited a bright purple pigmentation. The organism responsible was isolated and identified, primarily because of the relative ease with which this was accomplished. It was found to be *Chromobacterium ianthinum*. Plate counts of this organism never exceeded 10,000 per gram of sand and evidence of its presence was apparent only in the 18-in., 24-in. and 30-in. levels of sand and in the final effluent.

The examination for antibiotic-producing species, with particular emphasis upon the *Streptomyces sp.* and other organisms generally regarded as soil forms, gave negative results throughout.

## Discussion

### *General Heterotrophic Bacteria*

Extreme variation in plate counts of the species present and in total plate counts caused considerable difficulty throughout this study.

It was found that the highest total plate counts, and counts for identified organisms, were obtained in the earlier plating series, which were made during November and December when the dosing rate was 300,000 g.p.a.d. and air temperatures were rather low. Considering all factors, it would appear that high loading rates were responsible for the high counts obtained during those months. Strictly on a speculative basis, it should be noted that some investigators have attributed high bacterial counts in sewage in winter to a decrease in bacteria-eating plankton caused by the low temperatures. Another possibility is the higher death rate at warmer temperatures. All bacterial counts obtained, after the "rest" period and with lower dosing rates, were found to be considerably less than in the earlier series.

The occurrence of certain genera and species of the general heterotrophic bacteria at given levels of the bed was fairly consistent throughout the study. Members of the genus *Flavobacterium* were the most prevalent bacteria present at the 300,000-g.p.a.d. loading rate in the surface, 12-in., and 18-in. levels of the filter, but were only the second most numerous in the 6-in. level. No demonstration of the presence of members of this genus could be obtained in the 24-in. and 30-in. levels. *Flavobacterium aquatile* was the predominant species of *Flavobacterium* present in the surface, 6-in., 12-in., and 18-in. levels of the filter.

Members of the genus *Bacillus*, at the 300,000-g.p.a.d. loading rate, were the most numerous types found in the 6-in. and 30-in. levels, and were the second most numerous in the surface and 12-in. levels. At the 150,000-g.p.a.d. dosing rate the bacilli outnumbered the *Flavobacterium*. Various species of this genus were found in every level of the filter, with the two most often found being *Bacillus cereus* and *Bacillus alvei*. *Bacillus alvei* was often rather troublesome, due to its variability in morphological, physiological, and cultural characteristics.

At least one member of the genus *Alcaligenes* was found in all levels except the 12-in. and 30-in. levels. *Alcaligenes bookeri* was the most numerous organism of the 24-in. level and the second most numerous in the 18-in. level. The examination of a larger number of samples would possibly have given more valid results by showing *Alcaligenes* in greater or lesser number at all levels.

Species of *Streptomyces* and *Nocardia* were present in various levels of the filter and constituted the less numerous group of the major genera.

*Zoogleal Bacteria*

It was found that a majority of the zoogloea-forming bacteria in the filter were located in the upper layers of sand. These organisms were present in the surface and 6-in. levels in approximately the same numbers, as nearly as could be determined. Flocculent growth was obtained in dilutions up to and including 1:100,000,000,000 in both levels, which indicates a minimum count of 100,000,000,000 zoogleal bacteria per gram of sand. No visible flocs were formed at dilutions of 1:1,000,000,000,000 or higher.

It is significant that the presence of floc-forming organisms was not detected below the 12-in. level of the filter, even when using the relatively low dilution of 1:1,000,000. This would seem to agree with the earlier observations of one of the authors (4) in which he assigned the preponderance of the purification process to the first 12 in. of sand on the basis of the protozoan population in this region.

The apparent absence of appreciable numbers of these zoogleal bacteria below the 12-in. level may possibly be explained by either, or both, of the following conditions: (1) a lack of sufficient food materials in the 18-in. and 24-in. levels to support a large population of these bacteria, due to the activity of the zoogloea and other bacteria in the upper portions of the filter; and (2) because these zoogleal bacteria require highly aerobic conditions for growth, there may be an insufficient supply of atmospheric oxygen below the 12-in. level. Inasmuch as nitrification occurs in the bed, it would appear that the first explanation is the more valid. The minimum count of zoogleal organisms at the 12-in. level was 100,000,000 per gram of sand. No visible flocs were formed at dilutions of 1:1,000,000,000 or higher.

*Miscellaneous Studies*

The decrease in numbers of coliform organisms was continuous throughout the filter. The greatest numbers occurred in the surface level of sand (Figure 3). This is probably best explained by the character of the sand at this level. The surface sand screens out the larger organic particles during filtration and after a considerable length of time, this organic matter forms a matted layer about ¼-in. thick, which acts as a highly retentive filter and aids in the removal of coliforms. Reduction in numbers continues at deeper levels of the sand, but the decrease is much less marked between the lower levels than it is between the surface and 6-in. levels. Mechanical removal probably exerts the greatest influence in this picture, but the effect of adverse conditions for these organisms cannot be disregarded.

Fecal streptococci were found in all levels of the filter and in the primary and final effluents. However, too few samples were examined to indicate more than just a very general trend. Only a 20 per cent reduction in their numbers occurred during passage through the filter. This does not compare favorably with the 95 per cent removal of coliform organisms and the usual 98 per cent removal of B.O.D. by the filter. A consideration of the results obtained shows that the fecal streptococci apparently have little value as indicators of the ability of the filter to remove the pollutional load. A possible explanation for the lack of retention of these organisms may be their relatively small size. If such is the case, it follows that a finer sand would produce a considerably higher removal of the streptococci.

The tests for antibiosis on representative species isolated during this study showed a complete lack of inhibitory powers. These results gave no support to the hypothesis sometimes offered that decreases in numbers of pathogenic and non-pathogenic enteric bacteria may be due in part to antibiotic action.

*Physiological Properties of all Groups of Bacteria and Their Relation to Sewage Purification by Sand Filtration*

The composition of sewage varies considerably, depending upon its sources, but it has been established that sewage generally contains cellulose and other carbohydrates, proteins, fats, and urea, and decomposition products of all of these. These constituents render sewage a good culture medium for the growth of many types of microorganisms.

The counts of the zoogleal bacteria were very high, suggesting their importance in the work of the filter. Studies by Wattie (17), Butterfield (3), and others indicate the ability of these organisms to adsorb and assimilate organic matter of various kinds, including carbohydrates. This ability is thought to be due in large measure to the adsorptive properties of the capsule of the organisms. Food is thus concentrated in the floes where, possibly, it is worked on by other bacteria. However, as no physiological tests were made upon these bacteria, conclusions of their value in this type of purification must be drawn from the numerous studies made by various authors.

It was found that a majority (78 per cent) of the more important general, aerobic, heterotrophic bacteria present in the filter possessed the power to hydrolyze gelatin, and 65 per cent of these bacteria were able to peptonize milk. Approximately 35 per cent of the predominant species were able to utilize ammonium media as a source of nitrogen, whereas 52 per cent could not. Reduction of nitrates was accomplished by 43 per cent of the predominant species, but 48 per cent were unable to accomplish reduction. Fifty-seven per cent of all cultures decomposed not less than two different carbohydrates with the production of acid.

The genus *Bacillus* was the most active, of all the predominant genera, in hydrolysis of gelatin, acid production from carbohydrates, and peptonizing milk. Members of the genus *Flavobacterium* produced hydrolysis of gelatin, but gave no indication of activity in carbohydrates.

It should be mentioned that bacteria of the coliform and fecal streptococcus groups may play a more important role in the decomposition of certain constituents of sewage than is generally accepted. It has been demonstrated that members of both groups are distributed throughout the filter, although usually found in small numbers when compared with other species of bacteria present. Observation of the descriptive charts (4) for the coliform organisms will show that all are active in the fermentation of a number of carbohydrates. Certain of the coliform organisms generally found in sewage are proteolytic and many have the power to reduce nitrates.

A comparison of the physiological properties of coliform organisms and fecal streptococci shows that the activity of the latter in carbohydrate metabolism is even greater than that of the coliforms (acid is produced, in most cases, in only 8 hr.) It is readily observed that these streptococci, regardless of their small numbers, are capable of producing major changes in the carbohydrate content of the sewage in a rather short period of time.

A general consideration of the physiological properties of all of the bacteria found during these studies will show that a wide variety of organic compounds are utilized as a source of energy. In spite of the differences between laboratory conditions and those found in the filter, it is only reasonable to assume that many of the same physiological reactions are extant in the filter.

Since the manuscript of this article was submitted for publication, the re-

port of McKinney and Horwood (19) has appeared. It should be noticed that three genera of general heterotrophs mentioned by them were found in the sand filters in the work herein reported; namely: *Flavobacterium*, *Bacillus*, and *Nocardia*. In the case of the *Bacillus*, identical species were found to be significant; that is, *B. cereus*. It is possible that some of the zoogleal-forming bacteria enumerated in the work reported here may have been some of the forms discussed by McKinney and Horwood, but work now in progress indicates that the floc-formers here reported as zoogleal bacteria are similar to those reported by Wattie (17) in work already mentioned. The similarity of the bacterial groups in activated sludge and in intermittent sand filters needs further study and conclusions on the work done by these groups of organisms in the two processes cannot be drawn at this time.

## Conclusions

1. An increase in dosing rates produces a marked increase in the bacterial population of the filter.

2. Fourteen species of general heterotrophic bacteria were isolated from various levels of the filter, with members of the genera *Flavobacterium* and *Bacillus* the predominant types.

3. The higher dosing rate yielded results showing *Flavobacterium* as the more predominant genus, but with the lower dosing rate (150,000 g.p.a.d.) the numbers of the genus *Bacillus* exceeded the *Flavobacterium*.

4. The presence of certain species at all times during the course of this study indicates that they are adapted to this environment and are carrying on metabolic processes.

5. The presence of zooglea-forming bacteria in great numbers was demonstrated in the upper 12-in. of sand. The counts of these zoogleal bacteria, when compared with the counts of the general heterotrophic bacteria under similar conditions of operation, showed that in most cases they outnumbered these general heterotrophic organisms.

6. Decomposition of the usual constituents of sewage may be readily explained by the physiological properties and interrelationships of the more numerous species present in the filter.

7. The greatest numbers of coliform organisms occur in the surface level of the filter, the number of these organisms decreasing with increasing depth of sand.

8. Fecal streptococci were found to exhibit no great decrease in number in the final effluent from those originally found in the primary sewage applied. A decrease was found in most levels of sand, although not as marked as in the case of the coliforms.

9. There is at present no apparent relationship between the decreasing numbers of coliforms or fecal streptococci with increasing depth of sand and their decrease between the sewage applied and the effluent from the filter.

10. Coliform organisms and fecal streptococci may play an important part in the rapid decomposition of the carbohydrates found in sewage, as evidenced by their continuous presence in the filter and their great activity in carbohydrates under laboratory conditions.

11. No results were obtained in support of the view that decreases in enteric bacteria by sewage filters are due to the presence of antibiotic-producing microorganisms.

12. There is a decrease in count of all species of bacteria as the depth of sand increases; however, all species do not decrease at equal rates.

## Acknowledgment

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# SHALLOW CLARIFIER AT WHEATRIDGE, COLO.

By Carroll H. Coberly

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The Wheatridge sewage disposal plant serves a district on the west boundary of Denver, Colo., and handles the sewage from about 30 mi. of sewers. The plant is a secondary treatment plant having standard trickling filters and provisions for the installation of secondary clarifiers as soon as the funds are available for this development.

As there were no previous sewer facilities and there were only 1,200 houses built out of the 5,000 houses possible in the area, it was decided to build the plant in units. The original construction and the bond issue were to take care of the two units. This was divided into headworks, a pumphouse, and a digester large enough to handle two units. It was proposed to build two clarifiers and two trickling filters, but at the start only one clarifier and one trickling filter were built, with enough money left from the bond issue to build the second clarifier and trickling filter when it became necessary.

Sewage enters the plant from an 18-in. sewer, passing first through a sand trap, then through a comminutor and a Parshall flume, where the flow is measured and recorded on a flow chart in the pumphouse. The flow then goes to a division box that divides the sewage between two clarifiers. The overflow from the clarifiers goes to two sumps in the pumphouse, where two pumps on each sump alternate and pump the flow over the trickling filters. The sludge from the clarifier is pumped directly into a floating-cover digester. Sludge from the digester goes to six sludge drying beds. The effluent from the trickling filters can either be recirculated through the clarifier or go directly to the outfall weir. There is also provision at the division box to take the effluent from the filter to secondary clarifiers when they are built.

An interesting thing about this plant is the clarifier, which was built on a surface area basis. The area was obtained by the formula:

$$\text{Quantity} = \text{Area} \times \text{Settling rate of particle}$$

A settling rate of 0.001 ft. per sec. for peak flow was used, in accordance with the Stokes' Law application previously advocated by Poepel (1)(2)(3) and Coberly (4).

The standard calculations for this clarifier were not made. A peak flow of 1.45 cu. ft. per sec., or an amount equivalent to take care of 1,250 houses, was used. This was based on the actual water use in the district.

The clarifier itself (Figures 1 and 2) has a 6-ft. diameter center compartment with walls extending to the bottom of the clarifier. The effluent enters the center compartment through a pipe in the bottom. A cone 2 ft. from the surface breaks up the influent velocity and distributes the flow evenly over the entire top of the center compartment, where it flows out over the center compartment wall and under a baffle into the main settling chamber of the clarifier.

The sludge scraping mechanism is suspended from a traveling bridge. There are two scrapers—one in the center compartment and one in the settling compartment, so that the bottom of the clarifier is scraped clean at every revolution of the bridge. The bridge itself is carried on a center col-

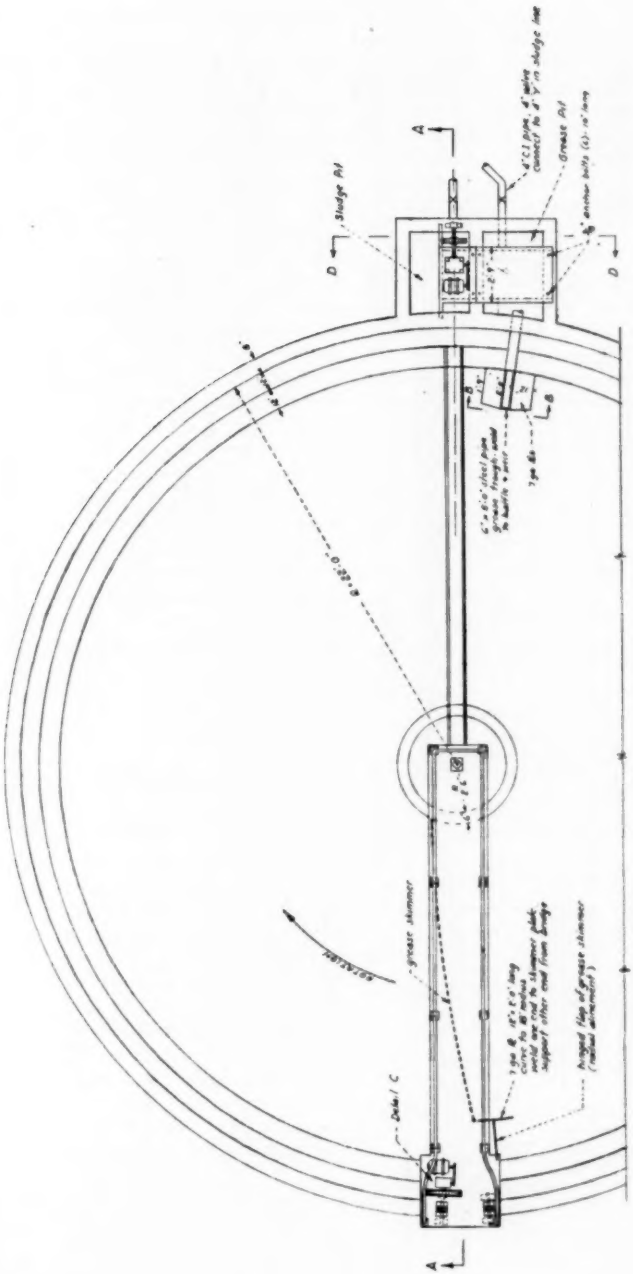


FIGURE 1.—Plan of shallow clarifier.

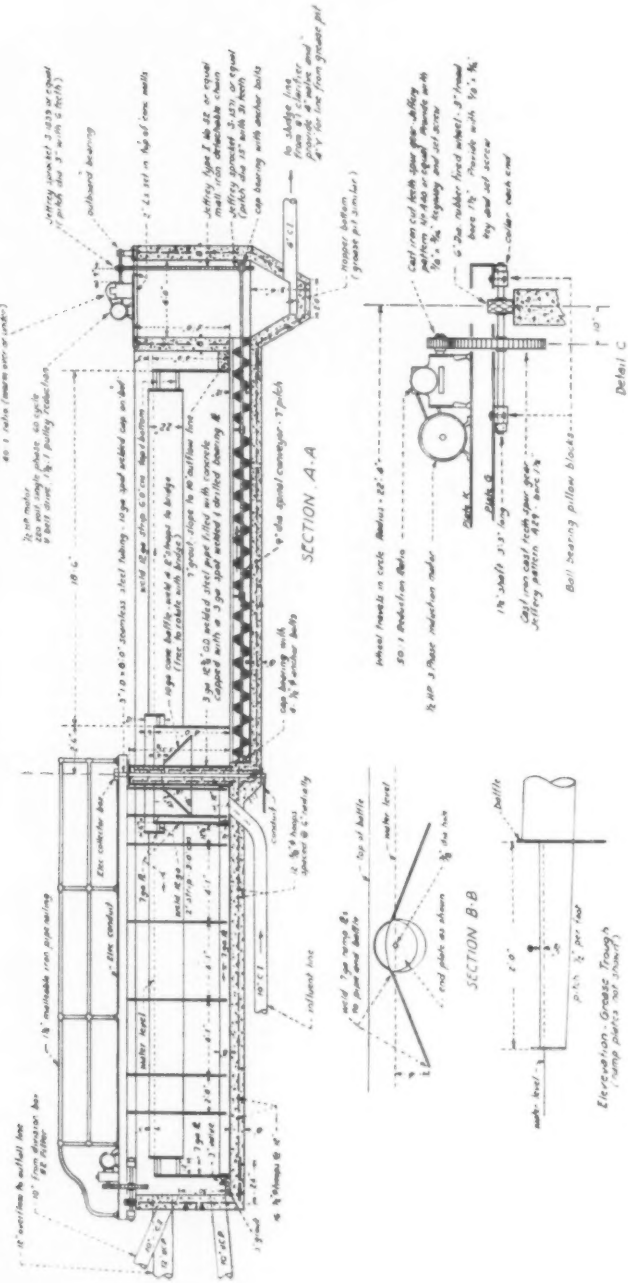


FIGURE 2.—Details of shallow clarifier.

umn and has two rubber-tired wheels 6 in. in diameter and 3 in. wide traveling on the outside wall. One of these wheels is geared to a ½-hp. motor. The sludge is scraped around the clarifier into a trough 12-in. deep extending from the center column into a sludge pit on the outside of the clarifier. In this trough a screw conveyor operates continuously, pushing the sludge into the sludge pit. A separate ½-hp. motor drives the screw conveyor through a gear reducing box and a chain drive. The screw conveyor has a tendency to concentrate the sludge in the sludge pit and has at times raised the level of the water surface in the sludge pit as much as 3 in. above the water level in the settling compartment.

The clarifier is only 4 ft. deep; it is 42 ft. in diameter to the overflow weir. The wall on which the cleaning mechanism runs is 44 ft. in diameter. A steel baffle placed 1 ft. from the outside wall acts as an overflow weir for the settling compartment. Inside of this overflow weir a steel scum baffle holds back the grease in the settling compartment. The 1-ft. space outside the overflow weir acts as an auxiliary storage for the sumps in the pumphouse.

A criticism that has been made of shallow settling tanks is that they are affected very much by wind currents. In this tank this has not been the case.

One of the main features of the clarifier is the very long overflow weir. Design of the clarifier on an area basis necessitates a much longer weir than if based on detention time. The result of the long overflow weir is that the uprising current and the velocity of approach is not sufficient to carry solids up and over the weir. Another feature of the tank is the complete killing of the influent velocity in the center compartment, due to the cone, and the fact that bottom currents have been eliminated entirely by carrying the center well wall to the tank bottom. The sludge scraping mechanism and the grease skimmer both work perfectly. There has never been a case, even with the low flow of 70 g.p.m., of septic sludge in the clarifier, as the sludge is removed completely at every revolution of the bridge, which takes about 15 min.

As the overflow weir is so long, the flow follows down the outside of the weir. It was early observed that a slime built up on the outside of this weir had the same characteristic as the slime in the filters, indicating that a certain amount of oxidation took place on the outside of the weir.

The tests are not entirely conclusive, as they have not been made at regular intervals and were not made on composite samples. Also, facilities were unavailable for any but suspended solids tests. However, these tests, being grab samples and always taken at the peak flow, showed a consistent removal of 60 to 70 per cent. One test, after the clarifier was about 30 per cent overloaded, showed 52 per cent suspended solids removal.

The second clarifier is now under construction. Because of the excellent performance of the original clarifier, there was no question as to changing to another type of clarifier.

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# DETERMINATION OF ACTIVE CONTENT OF ANIONIC-TYPE DETERGENTS BY THE METHYLENE-BLUE METHOD

In an effort to keep abreast of developments in all phases of the synthetic detergent problem, the Federation headquarters office has been in contact with the larger manufacturers of these materials. One of the major obstacles to the intelligent investigation of the effect of syndets in sewage works has been the lack of analytical means for determining the concentration of active detergent present in the sewage. It is expected, therefore, that the method reported here, as modified by the research laboratory of a detergent manufacturer from a method originally reported by J. H. Jones in the *Journal of the Association of Official Agricultural Chemists*, **28**, 398 (1945), will prove of considerable interest.—Ed.

In presenting this method it should be pointed out that it is for the determination of the active content of only anionic-type synthetic detergents. However, because the quantity of this type of syndet produced commercially far outweighs both the cationic and nonionic types, it would seem reasonable to assume that the bulk of the syndets present in sewage would be of the anionic type.

Although use of the method for an unknown sample requires the assumption of a mean molecular weight for the detergent, the alkyl aryl sulfonate type of anionic detergent is so common that a value of 350 should approximate the mean molecular weight of the average anionic detergent.

## Principle

Sulfonated or sulfated surface active agents react with methylene-blue chloride in aqueous acid solution to form a blue complex. This reaction may be represented by

$$RSO_3^- + MB^+ \rightarrow RSO_3MB$$

in which $RSO_3^-$ represents the anion of the detergent and $MB^+$ the cation of the methylene-blue dye. This colored complex is soluble in chloroform and under suitable conditions can be quantitatively extracted from the aqueous solution, the excess methylene-blue chloride remaining in the aqueous layer. The percentage of detergent can be calculated by measuring the optical density of the extracted solution, using chloroform as a blank, and referring to a standard curve prepared from data obtained by using known amounts of the same type detergent. Although the accuracy of the method is not as great as desired, the method is useful for analyzing samples of low active content, preferably less than 2 per cent.

## Details of Method

### *1. Apparatus*

1.1. Separatory funnels, pear-shaped, 125 ml.

1.2. Volumetric flask, glass-stoppered, 50 ml.

1.3. Fisher electrophotometer, Model 7–101AC, equipped with a 650-m$\mu$. filter and micro cells.

### *2. Reagents*

2.1. Chloroform, U.S.P. grade (Merck).

2.2. Methylene-blue chloride, 0.1 per cent aqueous solution. Dissolve 0.100 g. of methylene-blue chloride (National Aniline Div., Allied Chemical and Dye Corp.) in distilled water and dilute to 100 ml.

2.3. Hydrochloric acid, c. p., coned., sp. gr. 1.19.

2.4. Cotton. A non-sterile, non-surgical bleached variety similar to that distributed by Johnson and Johnson, Chicago, Ill.

*3. Procedure*

3.1. Prepare an aqueous solution of the sample to contain between 50 and 300 gammas of active content per milliliter (see 5.1) and pipette 1 ml. of this solution into a 125-ml. separatory funnel containing 20 ml. of distilled water. Add, in the following order, 3 to 5 drops of concentrated HCl, 1 ml. of methylene-blue chloride solution, and 20 ml. of chloroform. Shake for 1 min. and let stand until the two layers have separated. Draw off the chloroform layer into a second separatory funnel and repeat the extraction of the aqueous solution with a second 20-ml. portion of chloroform (see 5.2). Combine the two chloroform extractions in the second separatory funnel. Add to the combined extracts 20 ml. of distilled water containing 3 drops of concentrated HCl, shake for 1 min., and allow the chloroform layer to settle. Filter the chloroform layer through a small wad of cotton placed in a dry funnel and collect the filtrate in a 50-ml. volumetric flask. Wash the cotton with chloroform, collecting the washings in the volumetric flask, but do not exceed a total volume of 50 ml. Make up to the mark with chloroform and mix thoroughly.

3.2. Measure the optical density of this solution (see 5.3), against the chloroform as a blank, in the electrophotometer using the 650-mμ. filter and the micro cells. Obtain the gammas of

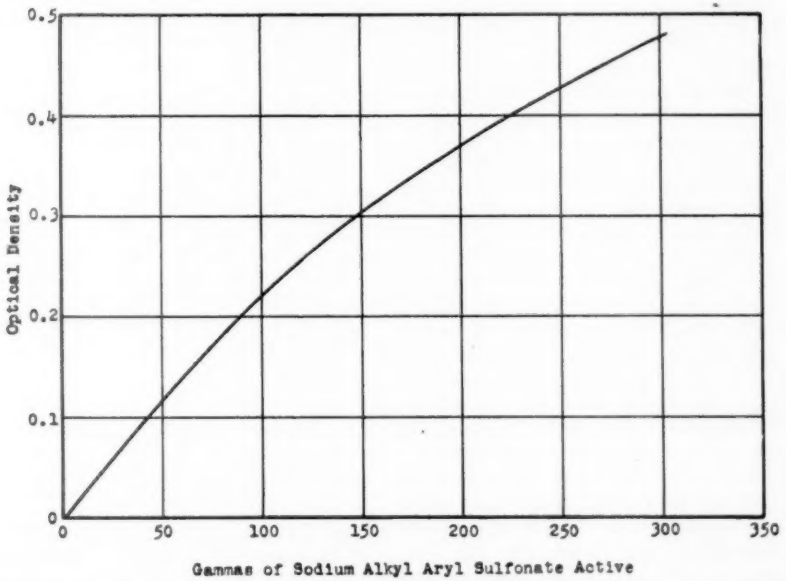


FIGURE 1.—Optical density by electrophotometer at a wavelength of 650 mμ. against chloroform blank using micro cells.

active material present in the aliquot by referring the density reading to a graph of the type shown in Figure 1, prepared by plotting the optical density readings of solutions of known active content (varying from 0 to 300 gammas) against the gammas of active contained in the corresponding solutions.

*4. Calculations*

4.1. The concentration of active material in the sample can be calculated from

$$\frac{G \times 100}{W \times 1{,}000{,}000} = \% \text{ active}$$

where $G$ represents the gammas of active and $W$ represents the grams of sample in the aliquot taken.

*5. Notes*

5.1. For samples of unknown active content, a preliminary test should be made. If this test indicates an active content too high for the calibration curve, dilute the colored solution with chloroform to obtain a solution of proper optical density. From the dilution requirements, the size of sample to be taken for analysis can be calculated.

5.2. The addition of an excess of methylene-blue chloride in step 3.1 is necessary in order to be assured that all of the detergent is converted to the blue complex. This condition is indicated by a blue color of the aqueous solution at that point of the procedure.

5.3. All photometric measurements should be made within one-half hour after the preparation of the solution, due to the instability of the blue complex when exposed to light.

5.4. Cationic-type surface active agents interfere with this determination, but their presence in combination with anionic-type detergents is not common. Soap in relatively high concentrations has only a slight effect on the result; 5 mg. of soap corresponds to about 0.02 mg. of sulfonate.

# Industrial Wastes

## RAG, ROPE, AND JUTE WASTES FROM SPECIALTY PAPER MILLS *

### II. Load Distribution and Effect on Total Mill Effluent

By Willem Rudolfs and N. L. Nemerow

*Rutgers University, New Brunswick, N. J.*

In a previous paper (1) it was shown that the wastes produced from specialty paper mills amount to 73,000 gal., containing dissolved organic wastes with about 750 lb. of B.O.D., per ton of paper. Studies of the distribution of the B.O.D., suspended solids, and total solids in the cook liquor and progressive washings were made to determine whether all of the wash water must be treated along with the cook liquor. Also, some effects of these wastes on the characteristics of the total mill effluent are illustrated.

### Pollutional Load of Cook Liquors and Wash Waters

The percentage of the total pollution load contributed by the cook liquors and wash waters was determined by using the closely estimated flow figures of each waste, determining their individual pollutional loads, and then combining these results to obtain the actual loads discharged in each total waste. It is significant that the polluting nature of the cooking liquors results from their relatively high concentration of B.O.D. and not from their suspended solids concentration (Table I). However, the beater-water wastes can be considered as stream pollutant because of their B.O.D. and suspended solids concentrations. Although the jute cook liquor represents only a volume of 6.3 per cent of the total cook and wash flow, it contains 37 per cent of the B.O.D. and 16 per cent of the suspended solids. Rope cook liquor, representing a flow of only 2.8 per cent of the total cook and wash waste, contributes 18 to 47 per cent of the B.O.D. and only 2 per cent of the total suspended solids. The rag waste illustrates the strength of the cooking liquors. Whereas the cook liquor waste represents a volume of only 1.8 per cent of the total, it contains 50 per cent of the total B.O.D. and 17 per cent of the total suspended solids. It is evident that the small volume of cook liquor can contribute up to 50 per cent of the total B.O.D., but the large volume of wash water used contributes half or more of the total B.O.D. and at least 83 per cent of the total suspended solids.

**TABLE I.—Relative Percentages of Total B.O.D, and Suspended Solids in Cook Liquors and Wash Waters**

| Type of Waste | Volume (%) | B.O.D. (%) | Susp. Sol. (%) |
|---|---|---|---|
| Jute cook | 6.3 | 37 | 16 |
| Jute wash | 93.7 | 63 | 84 |
| Rope cook | 2.8 | 18[1] | 2 |
| Rope wash | 97.2 | 82 | 98 |
| Rag cook | 1.8 | 50 | 17 |
| Rag wash | 98.2 | 50 | 83 |

[1] Because B.O.D. of rope wash water varies considerably, this may be as high as 47 per cent.

* Paper of the Journal Series, New Jersey Agricultural Experiment Station.

TABLE II.—Load Distribution in Cook Liquors and Progressive Beater Wash-Water Wastes

| Flow (%)[1] | | | Washing Time (hr.) | B.O.D. (%)[1] | | | Total Sol. (%)[1] | | | Susp. Sol. (%)[1] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jute | Rope | Rag | | Jute | Rope | Rag | Jute | Rope | Rag | Jute | Rope | Rag |
| 7.4 | 2.8 | 1.8 | 0 (cook) | 41 | 47 | 65 | 34 | 61 | 52 | 25 | 4 | 25 |
| 16.7 | 10.9 | 8.6 | ¼ | 74 | 68 | 77 | 64 | 76 | 62 | 56 | 34 | 33 |
| 25.9 | 19 | 14.3 | ½ | 85 | 80 | 83 | 77 | 83 | 70 | 71 | 54 | 42 |
| 44.5 | 35.2 | 26.9 | 1 | 93 | 90 | 92 | 88 | 90 | 79 | 88 | 75 | 50 |
| 63 | 51.5 | 39.4 | 1½ | 96 | 94 | 96 | 93 | 93 | 85 | 93 | 84 | 65 |
| 81.3 | 67.6 | 51.8 | 2 | 99 | 96 | 98 | 97 | 95 | 89 | 97 | 87 | 71 |
| 100 | 83.9 | 64.3 | 2½ | 100 | 98 | 99 | 100 | 98 | 91 | 100 | 93 | 77 |
| — | 100 | 76.8 | 3 | — | 100 | 99+ | — | 100 | 94 | — | 100 | 82 |
| — | — | 89.3 | 3½ | — | — | 99+ | — | — | 96 | — | — | 91 |
| — | — | 100 | 4 | — | — | 100 | — | — | 100 | — | — | 100 |

[1] Percentage of total accumulation.

## Total Load Contributed by Cooking Liquors and Progressive Washings

Composite samples of rag, rope, and jute mill wash waters were taken during the washing cycle and their progressive B.O.D., total solids, and suspended solids loads calculated (Table II). A graphical illustration of the percentage of total cook liquor and wash-water flow that must be included in treatment plans for a definite percentage of the total pollutional load, is shown in Figure 1. It is of considerable significance that the distribution of B.O.D. in the cook liquors and combined progressive washings is different from the suspended solids distribution, because the removal of both B.O.D. and suspended solids is necessary for efficient and complete treatment. Hence, the volumes of wastes representing at least 90 per cent of these types of pollution must be included. Some 90 per cent of the total B.O.D. is present in the first 35 per cent of the total flow, whereas 53 to 84 per cent of the total flow contains 90 per cent of the suspended solids. The reason is that B.O.D. is contributed mainly by dissolved and colloidal impurities absorbed on the cooked fibers and easily removed at the start of washing, but the suspended solids, arising from the continuous beating of the cooked fibers to shorten them to the desired length, are discharged during the entire washing cycle. If the first hour of wash water is included with the cooking liquor, 90 per cent of the B.O.D. is included in only 27 to 45 per cent of the total flow. The second hour of wash water contains mainly suspended solids that can be settled, and the third hour of wash is so weak that its treatment may be neglected. A study of the load distribution curve from another rope mill showed that, despite the variation in cooking and washing processes, it was almost identical with the first rope mill, indicating that the variation from mill to mill is no greater than the variations occurring within a certain mill.

## Effect of Wastes on Total Mill Effluent Character and Primary Treatment

Jute cook and wash-water wastes affect the total mill effluent, as well as the suspended solids reduction by plain sedimentation. This is shown by the following average results obtained in actual pilot plant experiments:

| Jute Cook and Wash Wastes Present | pH Range | Methyl Orange Alkalinity (p.p.m. $CaCO_3$) | B.O.D. (p.p.m.) | Susp. Solids Reduction (%) |
|---|---|---|---|---|
| No | 3.3–6.7 | 0 | 66 | 91 |
| Yes | 3.3–10.1 | 21 | 130 | 68 |

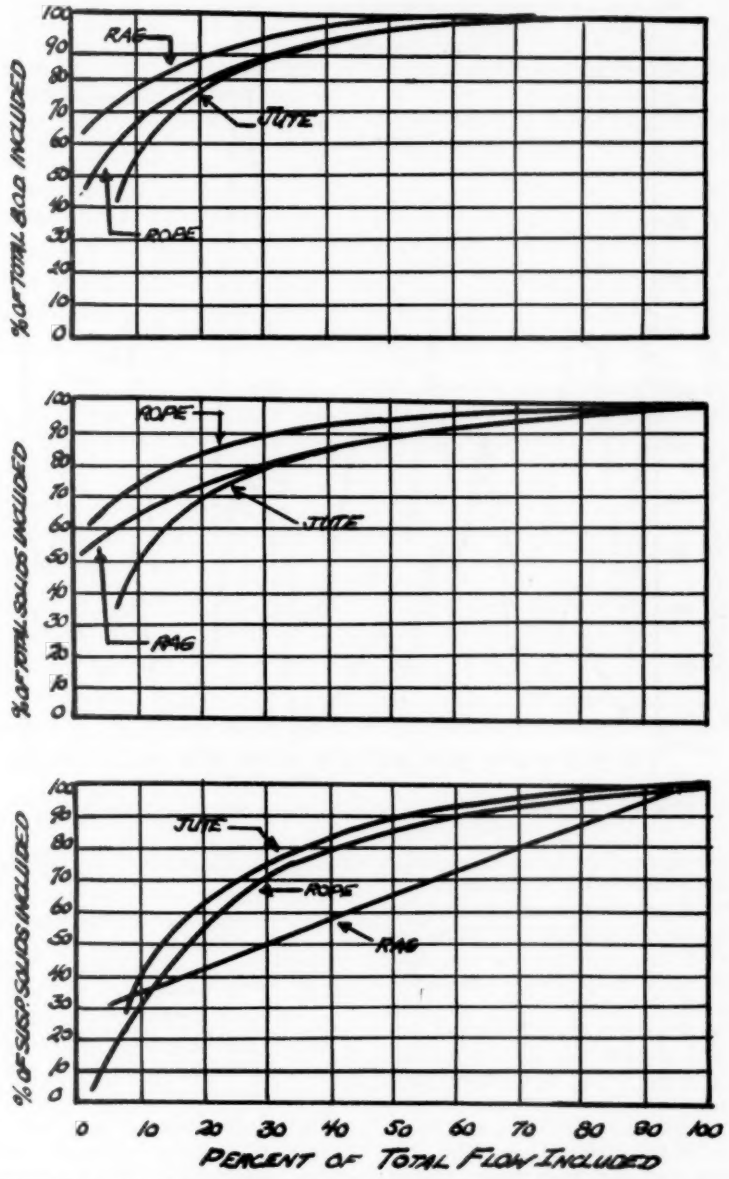


FIGURE 1.—Distribution of suspended and total solids and B.O.D. with progressive wash-water volume.

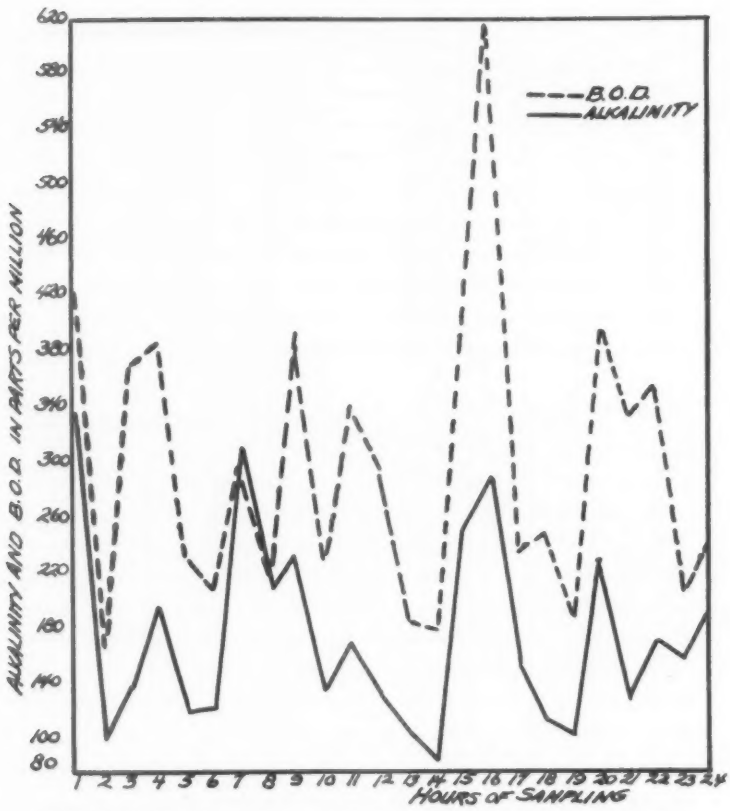


FIGURE 2.—Correlation between alkalinity and B.O.D. of rope mill effluent.

The presence of the jute cook and wash wastes increases the variation in total mill pH and methyl orange alkalinity, increases the average pH value and B.O.D., and decreases the suspended solids reduction by plain sedimentation. Because, in general, high alkalinity causes dispersion of finely divided matter, it is possible that the extreme variation in pH of the mill effluent from hour to hour has an adverse effect on the mechanical coagulation and flocculation of the suspended particles.

Jute cook and wash wastes also affect the chemical coagulation with lime of the total mill effluent, as shown by the following condensed summary of average results obtained in pilot plant experiments:

| Jute Cook and Wash Wastes Present | pH Range | Methyl Orange Alkalinity (p.p.m. $CaCO_3$) | | B.O.D. (p.p.m.) | Susp. Solids Reduction (%) |
|---|---|---|---|---|---|
| | | Range | Average | | |
| No | 2.5–7.1 | 6–55 | 26 | 57 | 91 |
| Yes | 2.5–9.6 | 0–80 | 40 | 100 | 83 |

The results illustrate that the discharge of jute cook and wash wastes causes considerable variation in pH and alkalinity of the total mill waste despite the mixing and equalization in an open flume and a flash mixing cham-

ber, and causes an increase in alkalinity and B.O.D. of the total mill effluent, as well as a decrease in the reduction of suspended solids after lime treatment. The probable reason for the decrease in suspended solids reduction is that the cook and wash wastes affect the pH value of the mill waste and addition of lime results in temporary overdoses and some dispersion.

### Effect of Rope Cook and Wash Wastes on B.O.D. and Alkalinity of Total Mill Effluent

Composite hourly samples of the combined mill effluent from a large rope mill were collected for a 24-hr. period. The alkalinity and B.O.D. values of these samples, considered to be correlated, are plotted in Figure 2. In general, when the alkalinity of the mill effluent increased, the B.O.D. increased, but not in direct proportion to the increase in alkalinity. The increase in alkalinity and B.O.D. was the result of an increased proportion of the cook liquor and beater wash wastes in the total mill effluent. Other mill wastes discharged simultaneously can alter the extent of the B.O.D. increase. It is possible for a mill to secure alkalinity and B.O.D. values of the mill effluent for a considerable period of time and by the use of an average curve approximately predict the B.O.D. of the effluent from the alkalinity values. Such a procedure would save the mill time, expense, and labor, but the percentage deviation occurring between the predicted value and the actual B.O.D. value must be determined by collection of a number of samples and analyses for alkalinity and B.O.D. to insure the accuracy of the method.

### Summary

An investigation of the load distribution in the cook and wash wastes of a specialty paper mill showed that the treatment of only the cook liquor and the first hour of wash water would include 90 per cent of the total B.O.D. in only about 36 per cent of the total combined cook liquor and wash-water waste flow. The small-volume cook liquor can contribute up to 50 per cent of the total cook liquor and wash-water waste B.O.D., but little of the suspended solids. Jute cook and wash wastes increased the range in pH and alkalinity, increased the B.O.D., and reduced the suspended solids reduction by plain sedimentation and lime coagulation of the total paper mill effluent. Rope cook and wash wastes caused an increase in B.O.D. and alkalinity in the total paper mill effluent. A method of determining B.O.D. of the mill effluent from its alkalinity value is suggested.

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# Stream Pollution

## ANALYSIS OF POLLUTED WATERS CAPABLE OF PHOTOSYNTHESIS

By W. E. Abbott

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When a full bottle of settled sewage is exposed to light it becomes very septic. It usually becomes black and may contain much dissolved hydrogen sulfide. Ultimately it turns green and the green becomes more intense. After a time oxygen gas is evolved in the light. A profound qualitative change has occurred. The senses reveal that the liquid has become innocuous. Microscopic examination shows that the green color is due to small chlorophyll-containing organisms. Much of the original organic matter has disappeared and much of the resulting carbon dioxide and carbon dioxide from other sources has been synthesized into organic matter. Above all, a liquid with a strong dissolved oxygen demand at all times has been converted into one which actually evolves oxygen in the light. The transformation can be accelerated by inoculation with green organisms. The attempt to exploit this transformation at Nottingham has been described (1).

The usual methods of sanitary chemical analysis do not reveal the beneficial extent of these great qualitative changes; neither are they very helpful for the purposes of record or control. It is true that the B.O.D. test usually shows a large decrease when the change takes place in a settled sewage, but an increase very often results when a river water is exposed. The suspended matter and acid permanganate methods often record increases. They cannot differentiate between recently synthesized organic matter and that which has been through the sewers. The B.O.D. test often shows a loss of oxygen when there is reason to believe that an increase of dissolved oxygen will actually result in the river.

It was felt that a new index must be devised which varied in an intelligible way with the results of observation. The principal measurable change in a polluted water in which green organisms are growing is the increasing ability to photosynthesize oxygen in the presence of the necessary nutrients. Therefore, it was decided (2) to measure the changes in the dissolved oxygen of portions of the suitably diluted sample after simultaneous incubation for comparatively short periods in the dark and in a source of light. It was necessary to standardize the illumination, as the rate of photosynthesis is dependent, within limits, on it. Exposure near a source of electric light proved disappointing, owing to heating effects. It was finally decided to use diffused daylight and to measure it by the release of iodine in a mixture of potassium iodide and sulfuric acid.

### The Hydrogen Iodide Actinometer

The light falling on the exposed bottle is measured by placing another bottle containing a mixture of sulfuric acid and potassium iodide beside it. Iodine is produced at a rate depending on the intensity of the light. Titration gives an integrated figure for the amount of incident light during the exposure. The device is known as an actinometer. The iodine produced by

exposing a standard mixture out of doors has been used for many years to record atmospheric conditions (3). A more sensitive mixture is required for use indoors or when immersed in turbid waters. Investigation showed that the rate of production of iodine increased with rising concentration of either reagent. A mixture of 40 ml. of 5 per cent potassium iodide and 40 ml. or normal sulfuric acid was finally adopted. The clear glass bottles used are of about 115-ml. capacity, stand on 3-cm. bases, and have glass stoppers. The mixture is supposed to be stable to light in the complete absence of air (4). It is advisable, therefore, to saturate both solutions with oxygen by shaking in the air immediately after preparation. The solutions should be made with glass-distilled water, as copper interferes.

### Recommended Procedure

Two 300-ml. glass-stoppered bottles are filled with the suitably diluted mixture. One is placed in diffused daylight, the other in the dark. An actinometer bottle containing 40 ml. of 5 per cent potassium iodide and 40 ml. of N sulfuric acid is placed beside the exposed bottle. After 4 hr. the dissolved oxygen is determined in both bottles and the actinometer bottle is titrated with N/40 sodium thiosulfate. The difference between the oxygen residuals is assumed to be the gross oxygen photosynthesized. An exposure causing the liberation of 4.0 ml. of N/40 iodine is taken as the standard amount of light and the actual observed oxygen difference is calculated to this value by

$$Y = (O_l - O_d) \times \frac{4.0}{A} \times \text{Degree of sample dilution}$$

in which $Y$ is the gross oxygen photosynthesized by the sample, $O_l$ is the final dissolved oxygen concentration in the exposed bottle, $O_d$ is the final dissolved oxygen concentration in the bottle kept in the dark, and $A$ is the actinometer titration in ml. of N/40 thiosulfate.

The degree of dilution should be chosen so that the value of $O_l$ does not much exceed 20 p.p.m. This will usually supply sufficient sources of carbon dioxide for the organisms. Variation of the degree of dilution within these limits had little effect on the value of $Y$ when using a diluting water with an alkalinity to methyl orange of 180 p.p.m. Owing to the supersaturation which often occurs in the exposed bottle, it has been found best to use the azide modification of the Winkler method of determining dissolved oxygen (5). There is some danger of losing gas with the larger number of manipulations in the Rideal-Stewart modification.

Table I records a test in which the value of $Y$ was determined in light of varying intensity by exposing a number of identical bottles and actinometer bottles in different parts of a room. $Y$ is not sensitive to comparatively small variations on each side of an iodine release of 4.0 ml. of N/40 thiosulfate. With experience, the bottles can be so sited that the titer at the end of exposure is not far from the desired 4.0 ml.

### Alternative Procedure

The 5-day B.O.D. test is so well established it was felt that some modification in which the bottles were illuminated during the test would be more acceptable to others in dealing with

**TABLE I.—Dependence of $Y$ on the Amount of Light Actually Received During Exposure**

| Actinometer Iodine Release (ml.)[1] | Increase in D. O. (p.p.m.) | $Y$[2] (p.p.m.) |
|---|---|---|
| 1.9 | 2.38 | 5.0 |
| 2.3 | 3.15 | 5.5 |
| 4.5 | 6.47 | 5.5 |
| 5.6 | 8.05 | 5.8 |

[1] Ml. of N/40 thiosulfate.
[2] Calculated to 4.0 ml. N/40 thiosulfate.

polluted waters containing agents capable of photosynthesis. The following procedure has accordingly been evolved:

After dilution, the bottle is placed in the dark incubator as usual. On the following day it is exposed in diffused daylight alongside an actinometer bottle until the iodine release of the latter is judged to be 4.0 ml. N/40 thiosulfate by comparison with a blank containing this amount of iodine and the same amount of acid as used in the test. This procedure is repeated on two subsequent days. Tests have shown that the results are not materially influenced by whether these two exposures are on the second and third, the second and fourth, or the third and fourth days. This allows some latitude in avoiding Sunday work. The third exposure should terminate at least 18 hr. before the end of the 5-day period. This procedure has the advantage that the temperature is under control in the incubator for most of the 5-day period. Samples which are very green usually show an increase in the dissolved oxygen over the 5-day period. In such cases, the dissolved oxygen change is shown as negative, as the normal loss of oxygen in the standard test is shown as a positive loss. The result, whether positive or negative, has been called the "illuminated oxygen demand" (or I.O.D.) for the purposes of subsequent discussion in this paper.

The amount of light received in the course of the three exposures during the test is believed to be less than the average amount in the Trent River below Nottingham. This belief is based on the results of a limited number of exposures of actinometer bottles in the river.

## Variation of the Suggested Parameters during the Growth of Green Organisms in a Sewage Liquid

Table II shows the progressive changes in *Y* and the I.O.D. when a filtered sewage seeded with *Chlorella* was exposed to light in a number of full stoppered bottles. The bottles were withdrawn for analysis at intervals as changes became visible and the contents were thoroughly mixed before analysis. It is seen that *Y* increased from zero to 78 p.p.m. and the I.O.D. changed from 182 to −126 p.p.m. Other analytical values are given for comparison. The standard B.O.D. fell from 186 to a minimum of 70 p.p.m. and then rose slightly. The increase in the non-volatile suspended matter is usual in this type of experiment. It is more probably due to a change in the carbonate equilibrium than to fixation of soluble mineral matter by the organisms.

## Discussion

*Y* is the gross oxygen photosynthesized under standard conditions, expressed in parts per million. It expresses the aggregate effect of all the chlorophyll-containing organisms in a mixed culture on a common scale. The standard conditions have been in use for 4 yr. and have undergone considerable modification in the light of ex-

TABLE II.—Effect of the Growth of Chlorella in a Filtered Sewage

| | *Y* (p.p.m.) | I.O.D. (p.p.m.) | 5-day B.O.D. (p.p.m.) | Suspended Matter | | Alkalinity (p.p.m.) | | Ammon. N. (p.p.m.) |
|---|---|---|---|---|---|---|---|---|
| | | | | Non-Vol. (p.p.m.) | Total (p.p.m.) | Phenol-phthalein | Methyl Orange | |
| At Start | Nil | 182 | 186 | 4.0 | 72.0 | Nil | 400 | 36 |
| I | 26 | −37 | 83 | — | — | 40 | 335 | 22 |
| II | 71 | −70 | 70 | 10.0 | 237.0 | 85 | 325 | 21 |
| III | 78 | −126 | 74 | 60.0 | 350.0 | 90 | 230 | 20 |

perience. In particular, the period of exposure has gradually been reduced from 2 days to 4 hr. The procedure is strongly recommended.

The illuminated oxygen demand procedure previously described is complicated and requires more attention than is customary in a routine test. Examination of a number of green effluents from the Nottingham irrigation areas has shown that the algebraic difference between the B.O.D. and the I.O.D. is roughly proportional to the gross oxygen photosynthesized ($Y$) in the shorter test. On the average, B.O.D. $-$ I.O.D. $= 2.6\ Y$. The advantages derived from the resemblance of the I.O.D. test to the B.O.D. test are illusory. Conditions in a river are so complex that no test can be accurately devised to reproduce them. In any event, a different amount of illumination would be required for each set of circumstances. If it be desired to allow for the ability to photosynthesize on the oxygen status of a stream, a formula based on the B.O.D. and $Y$ could be devised for each case. There is a limit to the realism which can be imparted to modifications of the B.O.D. test.

It is believed that in certain circumstances credit should be given for ability to produce oxygen in the light in assessing effluents.

## Summary

The oxygen photosynthesized by exposure to a definite quantity of daylight, as measured by the hydrogen iodide actinometer, is recommended as a means of classifying polluted waters in which chlorophyll-containing organisms have developed.

## Acknowledgment

Thanks are due to the Sewage Disposal Committee of the Nottingham Corporation for permission to publish this paper.

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# THE OPERATOR'S CORNER

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## FROTH FORMATION AND SYNTHETIC DETERGENTS

BY W. N. WELLS AND C. H. SCHERER

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Froth* formation has long been known to be a problem which shows up from time to time in the treatment of sewage in activated sludge plants. With the advent of synthetic detergents a few years ago, and their increasing popularity, there has been some feeling that those agents, because of their exceptional sudsing properties, might be acting to increase the frothing difficulties encountered.

Because of the current interest in this subject, an investigation was undertaken with two points in mind:

1. How can the formation of froth during treatment be controlled?
2. Do synthetic detergents contribute to frothing?

The resultant findings were that, for the conditions in the San Antonio plant, (a) frothing can be controlled by maintaining a sufficiently high concentration of mixed liquor solids in the aeration tanks and (2) the addition of high concentrations of synthetic detergents did not cause frothing.

### Control of Frothing

From personal experience and from comments in the literature (1) the tendency for a low recycled solids content to result in the occurrence of froth was known. So, also, was the value of a high solids content in preventing froth formation. Accordingly, the first approach was to determine the relationship between solids content and frothing under the conditions encountered in the San Antonio plant. To carry out this study, the content of recycled solids was controlled and appropriate observations were made on the accompanying frothing tendency. A discussion of this work follows.

The San Antonio sewage treatment plant consists of two independent units operating in parallel and treating a total of about 50 m.g.d. of raw sewage. Both units treat the effluent from primary sedimentation in diffused air aeration tanks. The tests were conducted on the newer of these two units—the West Plant—which consists of seven passes operating in parallel. All of the passes receive return activated sludge from a common channel, the flow of sludge to each pass being controlled by a gate valve. Thus, it is possible to adjust the solids content of any given pass to a desired level. The investigation was made on one pass, using the other six passes as a control. Prior to the beginning of the test the plant had been running at the relatively high suspended solids level of about 3,000 p.p.m. without froth forming on any of the tanks. Table I shows the results over a period of days

* The term "froth" has purposely been adopted by THIS JOURNAL in referring to the aeration tank problem as distinguished from the "foam" problem at sludge digestion units. It is hoped thus to preclude confusion in terminology. The two words are essentially synonymous in dictionary definition, which is considered to justify this arbitrary decision with regard to their application.

**TABLE I.—Effect of Mixed Liquor Solids Content on Froth Formation [1]**

| Date | Hour | Susp. Sol. (p.p.m.) | Froth Height (in.) |
|---|---|---|---|
| Mon., 10/22/51 | 8:00 AM | 2,600 | None |
| | 1:00 PM | 1,900 | None |
| | 3:00 PM | 1,400 | None |
| | 5:00 PM | 1,100 | 4 |
| | 7:00 PM | 1,100 | 14 |
| | 9:00 PM | 900 | 24 |
| | 11:00 PM | 800 | 36 |
| Tues., 10/23/51 | 8:00 AM | 600 | 36 |
| Wed., 10/24/51 | 9:00 AM | 1,100 | 16 |
| Thurs., 10/25/51 | 9:00 AM | 1,300 | 14 |

[1] Solids in the control tanks ran from 1,600 to 2,400 p.p.m. during these tests and no froth appeared on any of the controls.

when the solids content was dropped from 2,600 to 800 p.p.m. and then brought up to 1,300 p.p.m. again. It may be seen that when they fell below 1,400 p.p.m. froth began to appear.

Over the next weekend the solids were lowered to a level of 80 p.p.m. and then, starting on Monday, they were gradually raised to a level of 2,000 p.p.m. As they increased, there was a corresponding decrease of the froth level until none existed after the solids had passed a value of 1,300 p.p.m. (see Table II).

**TABLE II.—Effect on Froth Formation of Increasing Mixed Liquor Solids Concentration [1]**

| Date | Hour | Susp. Sol. (p.p.m.) | Froth Height (in.) |
|---|---|---|---|
| Mon., 10/29/51 | 9:00 AM | 80 | 66 |
| Tues., 10/30/51 | 8:00 AM | 200 | 70 |
| Wed., 10/31/51 | 8:00 AM | 100 | 70 |
| | 10:00 AM | 130 | 60 |
| | 1:00 PM | 345 | 24 |
| | 3:00 PM | 700 | 30 |
| | 6:00 PM | 1,000 | 6 |
| | 9:00 PM | 900 | 8 |
| | 12:00 M | 1,000 | 5 |
| Thurs., 11/1/51 | 3:00 AM | 1,150 | 4 |
| | 6:00 AM | 1,150 | 6 |
| | 9:00 AM | 1,300 | 4 |
| | 1:00 PM | 1,600 | None |
| Fri., 11/2/51 | 8:00 AM | 2,000 | None |

[1] Solids in the control tanks ran from 1,800 to 2,400 p.p.m. during these tests and no foam appeared on any of the controls.

For conditions prevailing in the plant at the time of the test, a solids

FIGURE 1.—Effect of low suspended solids (200 p.p.m.) in test pass (left) compared with normal suspended solids (2,400 p.p.m.) in control pass (right); no synthetic detergent added; influent at far end.

**TABLE III.—Relation of Synthetic Detergent Content to Froth**

| Test No. | Flow Through Test Pass in 5 Hr. (m.g.) | | | Mixed Liquor Susp. Sol. | | | | Syndet[1] Added During Test | | Results[2] | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Raw Sewage | Return Sludge | Total | Test Pass | | Control Pass | | (lb.) | (p.p.m.)[2] | Test Pass | Control Pass |
| | | | | Min. | Max. | Min. | Max. | | | | |
| 1 | 0.666 | 0.400 | 1.066 | 3,200 | 3,800 | 3,200 | 3,800 | 106 | 12 | Practically no froth (Fig. 2). | Practically no froth (Fig. 2). |
| 2 | 0.918 | 0.372 | 1.290 | 3,200 | 3,900 | 3,200 | 3,900 | 526 | 49 | No froth (Fig. 3a). | Practically no froth (Fig. 3b). |
| 3 | 0.918 | 0.388 | 1.306 | 2,700 | 3,600 | 2,700 | 3,600 | 1,050 | 97 | Practically no froth (Fig. 4a). | Practically no froth (Fig. 4b). |
| 4 | 0.878 | 0.388 | 1.266 | 2,700 | 3,000 | 2,700 | 3,000 | 1,050[4] | 250 | Very slight froth at point of addition, less as liquor progresses through pass (Fig. 5). | No froth at influent end, some as liquor progresses through pass (Fig. 5). |
| 5 | 0.892 | 0.364 | 1.256 | 2,600 | 3,000 | 2,500 | 2,800 | 1,050 | 100 | Almost no froth (Fig. 6a). | Very slight froth and more as liquor progresses through pass (Fig. 6b). |
| 6 | 0.863 | 0.146 | 1.009 | 900 | 1,000 | 1,400 | 1,500 | 750 | 89 | Small amount of froth (Fig. 7a). | Small amount of froth (Fig. 7b). |

[1] Pounds of synthetic added represent bulk detergent (Tide).

[2] P.p.m. conc. $= \frac{\text{Added syndet (lb.)}}{\text{Mixed liquor flow during test period (m.g.)} \times 8.33}$.

[3] In photographs, influent enters tank at end farthest from camera.

[4] This test discontinued after 2-hr. period, as it followed immediately upon the 97-p.p.m. test and was showing substantially the same results.

level of about 1,400 was sufficiently high to prevent frothing. These results are in general agreement with previous experience and fit in with the observations of Edwards (1), who said, "In 1941, before the synthetic detergent problem became important, we could cause foaming if the aeration solids

**FIGURE 2.—Test pass (left) and control pass (right) after adding 12 p.p.m. synthetic detergent; suspended solids in both passes, 3,200 to 3,800 p.p.m.**

FIGURE 3.—Test pass (a) after adding 49 p.p.m. synthetic detergent; no detergent added to control pass (b); suspended solids in both passes, 3,200 to 3,900 p.p.m.

were in the vicinity of 800 to 1,000 p.p.m. Although this is too low, ordinarily, for activated sludge, we would, on occasion get into that range."

The extent of the frothing as caused by extremely low solids content (200 p.p.m.) is shown by Figure 1.

### Effect of Syndets

The tests involving synthetic detergents were made on the same pass used for studying the effect of solids variation, the adjacent pass serving as a control. In this work, appropriate quantities of "Tide,"* representative of the synthetic detergents in general use today, were added at a constant rate at the influent end of the test aeration tank. Because the approximate time required during normal sewage flow for an increment of the mixed liquor to pass through the tank was 4.7 hr., the addition of synthetic dur-

* The Procter & Gamble Company cooperated in the tests and furnished the synthetic detergent.

FIGURE 4.—Test pass (a) after adding 97 p.p.m. synthetic detergent; no detergent added to control pass (b); suspended solids in both passes, 2,700 to 3,600 p.p.m.

FIGURE 5.—Test pass (left) after adding 250 p.p.m. synthetic detergent; no detergent added to control pass (right); suspended solids in both passes, 2,700 to 3,000 p.p.m.

ing a test was carried on for 5 hr. to insure a uniform distribution throughout the pass. Knowing the rate of flow, it was possible to determine the quantity of synthetic detergent to be added per unit of time to give any particular level of concentration of added synthetic. This amount is, of course, in addition to the synthetic detergent normally present in the sewage. The method of calculating the quantity to be added is shown in a footnote to Table III.

Varying amounts of synthetic detergent were added at three levels of recycled solids. In Tests 1 to 4 (Table III), the level of solids was held high (2,700 to 3,900 p.p.m.). In Test 5, it was maintained at an intermediate level (2,500 to 3,000 p.p.m.); in Test 6, at a low level (900 to 1,000 p.p.m.).

The effects of adding varying amounts of synthetic detergent at the influent end of the experimental pass, and also the behavior of the control pass, are shown in Table III and in the accompanying photographs. The pictures show the results at the end of each study so as to allow maximum time for the development of any effects which might come from the addition of the synthetic. In each case the influent enters at the end farthest from the camera. From an examination of the photographs and Table III, it may be seen that no objectionable buildup of froth occurred at any level of added synthetic detergent.

The surface of the aeration tank, in the absence of added synthetic, is characterized by small bubbles, generally less than 1 in. in diameter (see Figure 8). When these bubbles gather together to form a froth bank they are stable and have a "beaten-egg-white" appearance, which is typical of proteinaceous froth. In direct contrast, after the addition of higher quantities of synthetic detergent to a pass, much larger bubbles—6 to 18 in. in diameter —were formed (see Figure 9). These bubbles were very fragile. When they struck the side of the tank they would usually burst immediately, and in so doing even tended to break down many of the small bubbles, such as those formed when no synthetic is added.

In Test 4, in which the largest ad-

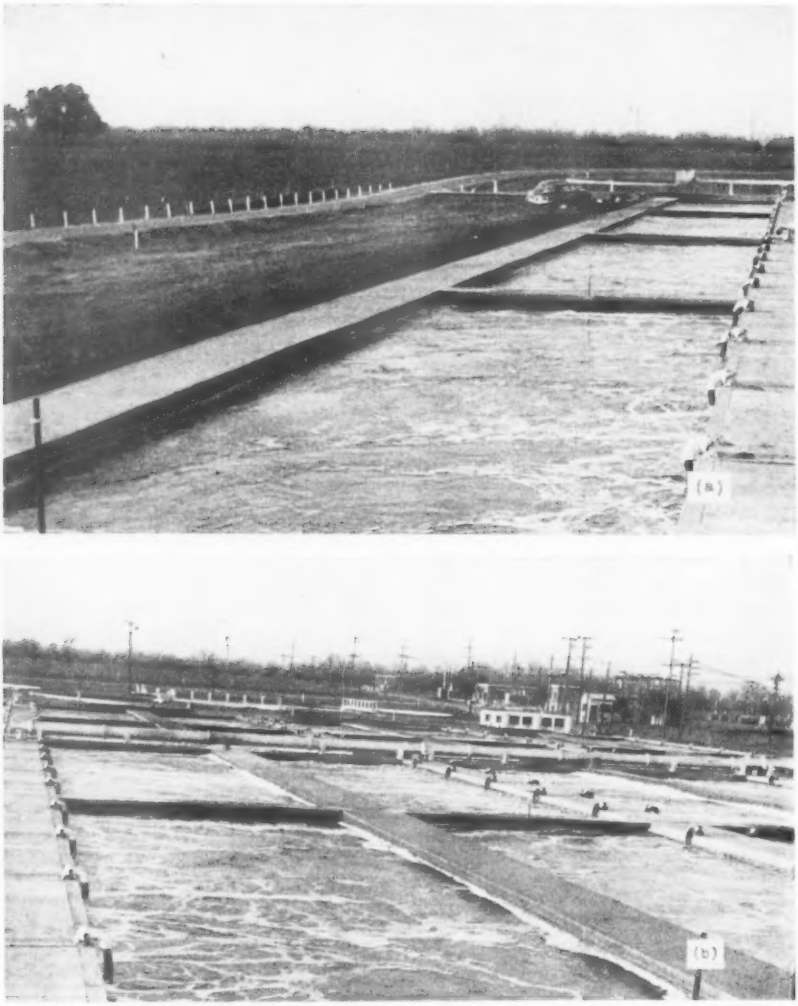


**FIGURE 6.—Test pass (a) after adding 100 p.p.m. synthetic detergent; no detergent added to control pass (b); suspended solids in both passes, 2,500 to 3,000 p.p.m.**

dition (250 p.p.m.) of synthetic detergent was made, a slight frothing occurred at the point of addition because of extremely high local synthetic concentrations. However, this froth dissipated as the liquor moved through the pass. This is exactly opposite to what occurs under conditions of natural frothing; that is, frothing due to low solids content. Natural froth is non-existent at the influent end and reaches a peak near the effluent end, as was seen in the studies involving low solids, and is shown in Figure 1.

The 250-p.p.m. level of synthetic detergent is believed to be several times

higher than occurs in practice, or than would occur if all of the soap business should be converted to synthetic detergents. This belief is based on the following considerations:

The synthetic detergent dumped into the tank was, of course, in addition to that already contained in the raw sewage. In effect, this was equivalent to having a concentration in the raw sewage even higher than that obtained from the added synthetic. Also, as has been established by Degens and vanderZee (2), at least a portion of the synthetic detergent in raw sewage is removed during primary sedimentation. Therefore, adding detergent at the influent end of the aeration tank gives a higher concentration in the tank than if an equal amount had been put into the raw sewage. In addition to these points, U. S. Department of Agriculture figures on soap and synthetic usage (3) show soap and syn-

FIGURE 7.—Test pass (a) with 900 to 1,000 p.p.m. suspended solids after adding 89 p.p.m. synthetic detergent; no detergent added to control pass (b) with 1,400 to 1,500 p.p.m. suspended solids.

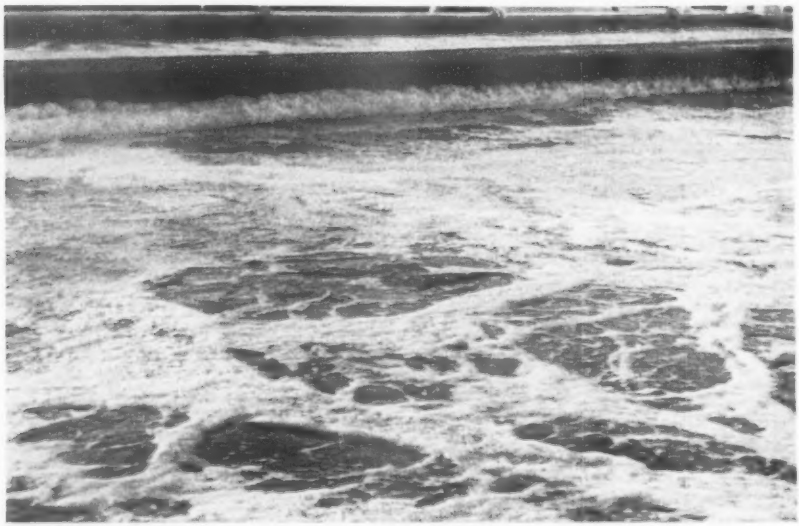

FIGURE 8.—Surface of aeration tank with no detergent added, showing typical small-bubble formation.

thetic usage in 1950 to have been 3,500,000,000 lb. and 1,200,000,000 lb., respectively.

The 1950 Census report gives a population of approximately 150,697,000. This means that, on the average, during 1950 approximately 23 lb. per capita of soap and 8 lb. per capita of synthetic detergent were used. Based on the Department of Agriculture's

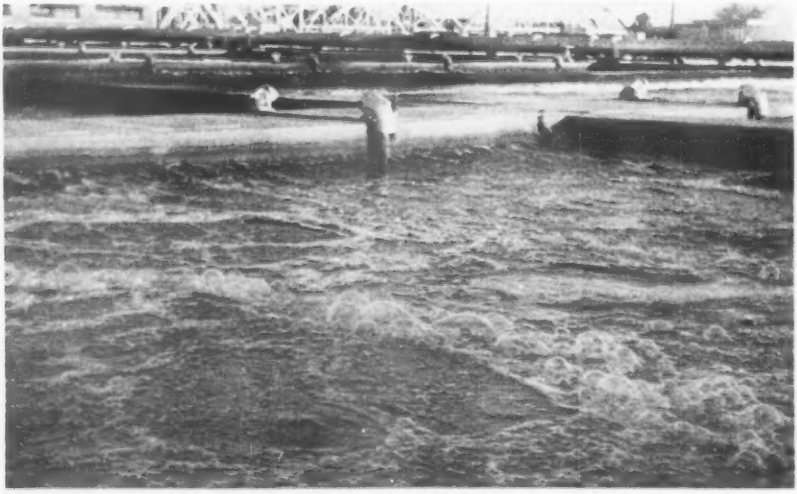

FIGURE 9.—Surface of aeration tank with high added synthetic detergent concentration, showing large fragile bubbles.

usage estimate of 200 g.p.c.d. of water (4), this works out to average concentrations of 13 p.p.m. synthetic detergent and 38 p.p.m. soap in raw sewage. This gives a total of 51 p.p.m. as contrasted with the 250 p.p.m. detergent added in the aeration tanks to sewage which already carried the amount of synthetic detergent currently in use.

Finally, the addition of synthetic detergent, even in the highest amounts used, had no adverse influence on the operation of the system; no detrimental effects were found in final sedimentation, neither was there any significant change in the final effluent B.O.D.

### Summary

1. The quantity of froth present on aeration tanks treating normal raw sewage was controlled by varying the amount of suspended solids in the mixed liquor. It was possible to make or prevent froth at will by decreasing or increasing the suspended solids.

2. Frothing has been kept under control at the San Antonio sewage treatment plant by maintaining the solids above the 1,400-p.p.m. level. (The plant is operated at 2,000 to 3,000 p.p.m., which is regarded as a range giving a suitable margin of safety.)

3. The direct addition of synthetic detergent to an aeration tank, even at extremely high concentrations, did not cause any objectionable frothing.

4. Even under conditions of low solids, where frothing is likely to begin to occur, the addition of synthetic detergent did not increase frothing.

5. Normal froth is non-existent at the influent end of the areation tank and builds up to a maximum near the effluent end. Conversely, when synthetic detergent is added at the influent end of the aeration tank in quantities sufficient to form any froth at all, it does not cause a buildup of froth as the mixed liquor passes down the tank, but rather the froth dissipates.

6. Throughout the course of the tests described, the addition of the synthetic detergent had no adverse effect on plant operation.

### References

1. Edwards, G. P., "1950 Operators' Forum." This Journal, **23**, 5, 679 (May, 1951).
2. Degens, P. W., Jr., and vanderZee, H., "The Influence of Synthetic Detergents on Sewage Purification." *Chem. Weekblad*, **45**, 166 (Feb., 1949).
3. "Fats and Oils Situation." FOS No. 149, Bur. Agric. Econ., U. S. Dept. of Agric. (May–June, 1951).
4. U. S. Dept. of Agriculture, Clip Sheet (Apr. 23, 1950).

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## TIPS AND QUIPS

### Hints on Froth Control

Regular occurrence of frothing in the diffused air activated sludge plant at Motherwell, England, sometimes to a height of 5 or 6 ft. above water level, has been successfully controlled by application of small quantities of mineral lubricating oil to the aeration tanks. The method is not used continuously, but only when reduced frothing is required to permit access to the tank walks for maintenance, or to prevent nuisance from froth carried out of the tanks by high winds.

Discovery of the de-frothing effect of the oil was accidental, originating with an oil leak in a Motherwell factory. It has been found that 0.5 pt. of oil sprayed on tanks totalling 0.5-m.g. capacity cleared up the frothing. On a purely volumetric basis this amounts to 0.11 p.p.m. However, the same results have been obtained with 0.5 pt. of oil applied to a 2.2-m.g.d. (Imp.) raw sewage flow reinforced with 0.93-m.g.d. (Imp.) activated sludge return.

The experience, reported in *The Wa-*

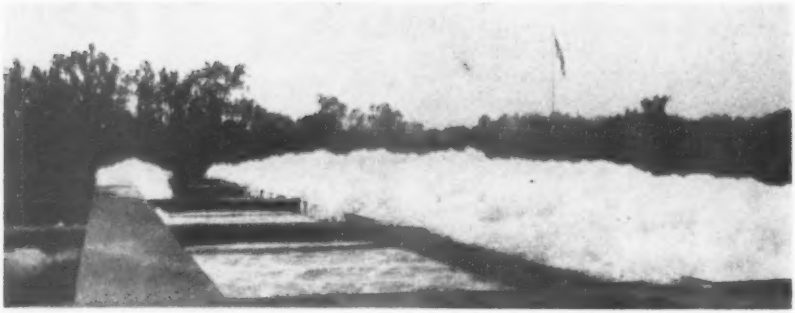


**FIGURE 1.—"Shaving lather" on aeration tanks at Cranston, R. I., with low solids concentrations.**

*ter and Sanitary Engineer*,* seems to confirm the general observations of Brunner † at Fort Wayne, Ind., concerning liquid surface application of oils to reduce frothing. J. McNicholas, author of the present article, closes his discussion with the following:

There are a few other observations on the subject which may be of general interest:

1. Frothing, as far as is known to the author, seems to be peculiar to the diffused air process. It has not been observed by him on Simplex, Howarth, Transaeration, or Kessener plants.

2. Frothing begins at the outlet end of aeration tanks and gradually develops towards the inlet end, which agrees with American reports. Froth is not often observed on the first bays of the aeration tanks at Motherwell.

3. Only when a plant is in good condition does frothing occur. Heavily loaded units do not froth, and with the onset of wet weather, froth which is present on tank gradually dies away when 3 × d.w.f. is being treated. Probably the extra load on the plant accounts for this, and also the fact that the concentration of froth-causing constituents becomes less.

4. Froth is usually most voluminous from late evening to early morning, when the actual aeration period is above the average.

5. After the weekly wash-day, froth generally increases, presumably because increased amounts of soap and detergents are present.

6. Numbers of *Chironomid* larvae are floated out of the activated sludge system by the froth and are found on the concrete walks after the froth has dispersed.

7. Bright sunlight appears to have a depressing effect on the froth. This is merely an impression, and no experimental evidence is put forward in support of the observation.

At Cranston, R. I., Superintendent W. C. Anderson finds that operation of the aeration tanks at the normal suspended solids content of 1,250 p.p.m. gives a fluffy froth (Figure 1), which has been taken for granted in that plant during the past few years. Present operation, at the 3,000- to 3,500-p.p.m. solids level, is free of froth trouble. This bears out the conclusions reported by Wells elsewhere in this "Corner," but also points to the possible requirement of additional air with the increased loading.

Preliminary test work at the Cranston plant with "Depuma," a defoaming agent marketed by American Aniline Products, Inc., of New York, indicated rapid disappearance of the froth in four bays of the aeration tank on addition of ⅓ gal. at the inlet by constant feed. Further tests to determine

* McNicholas, J., "A Method for the Control of Foam Produced in Activated Sludge Plants." *Water & San. Eng.*, **2**, 9, 416 (1952).

† Brunner, P. W., "Central States Sewage Works Association, 1950 Operator's Breakfast Forum." Remarks on "Frothing of Aerators." THIS JOURNAL, **22**, 9, 1238 (Sept., 1950).

minimum required additions of the defrother were abandoned when control was accomplished by increasing the mixed liquor suspended solids.

It is understood, also, that another defoaming agent, "Swift's Sanitary Defoamer," manufactured by Swift & Co., of Hammond, Ind., has been tested and is being used by New York City to control frothing. The same product is also understood to be under test by the city of Los Angeles, although no reports of the findings are available.

## Digester Supernatant Control

An interesting method of controlling his digester supernatant was described at the 1951 Fall Meeting of the New England Sewage and Industrial Wastes Association by Walter C. Anderson, superintendent of the Cranston, R. I., sewage treatment plant. In Mr. Anderson's own words:

> The problem of returning our 1.5 per cent solids sludge supernatant to the primary tank seems to have been solved by elutriating this sludge. The overflow liquor from the elutriation tanks passing into the primary tank has no effect on that unit's efficiency. The elutriation of the supernatant sludge results in the production of one-fourth as much sludge with a solids content of 3.75 per cent. In other words, elutriation concentrates the solids, which can then be filtered directly or returned to the digester. Without this processing, the supernatant sludge sent directly to the primary tanks would result in a slow build-up of sludge in the bottom of the tank, with consequent increase in sludge pumping rates back to the digester. The cycle was cumulative, as the more we pumped to the digester the more we drew. Perhaps just holding the supernatant sludge in a tank may accomplish the same results with a possible savings of plant water.
>
> Sludges with more than 5 per cent solids are reduced in solids content by elutriation and weak sludges are increased. The resulting elutriated sludge seems to leave from 3.75 per cent to 5 per cent solids content. In other words, elutriation produces a washed sludge of from 3.75 to 5 per cent solids, regardless of the original concentration.

## Vitamin $B_{12}$ from Milorganite

Dried activated sludge from the Milwaukee, Wis., sewage treatment plant, sold in all parts of the United States and in Canada, Mexico, and the Hawaiian Islands under the name of "Milorganite," has been found to be one of the richest sources of vitamin $B_{12}$ yet discovered. The vitamin, currently in demand for stock feed supplementation, occurs in a concentration of 2 to 10 micrograms per gram (1 to 4 milligrams per pound). Processes developed in the laboratory have already been used successfully in pilot-plant operations to prepare vitamin $B_{12}$ concentrate of relatively high potency (25 to 50 milligrams per pound of solids) from Milorganite.

The processes developed, which are covered in a patent application currently pending, appear to be both convenient and economical. Because concentrates of vitamin $B_{12}$ are in such demand for the production of pure vitamin, the possibility of large-scale production of the concentrates from Milorganite is being investigated.

## Booklet on Civil Defense Protective Equipment

What the well-equipped civil defender will wear and use is shown in a booklet entitled "Civil Defense Protective Equipment," recently published by Mine Safety Appliances Company. The 28-page booklet offers an outline of action and a table of equipment for the various civil defense services. Full descriptions, both practical and technical, are given for every piece of equipment mentioned.

As public service employees, sewage works personnel should be familiar with the municipal and areal civil defense planning of their locality and with the services and equipment involved. The booklet is available from Mine Safety Appliances Company, Braddock, Thomas and Meade Streets, Pittsburgh 8, Pa.

# Editorial

## SUDS AND SYNDETS

The San Antonio studies of the effects of synthetic detergents in producing froth at aeration tanks, as reported in this issue, will doubtless find a receptive audience among activated sludge plant operators. This is a significant project, and further results of the work will be awaited with great interest.

To date the San Antonio study has proved fairly conclusively that froth formation is not likely to be troublesome in the presence of high concentrations of anionic detergents if 1,600 p.p.m. or more of suspended solids are carried in the mixed liquor. This will bring no solace to those who must operate at lower mixed liquor solids levels, because of process modifications or by reason of aeration limitations. Nevertheless some progress is being made, and the cooperative effort of the city of San Antonio, Proctor and Gamble, and Superintendent Wells and his staff is acknowledged with commendation.

It should be noted that the results at San Antonio do not "whitewash" synthetic detergents as the cause of aeration tank suds. Many activated sludge plants operated with low mixed liquor solids prior to 1940 without the voluminous froth that is frequently encountered today. Household garbage grinders are introducing increasing amounts of grease into domestic sewage simultaneously with the increasing concentration of synthetic detergents, and both of these factors alone or in combination may be contributing to the present difficulties. Whatever the cause, "the old gray sewage ain't what she used to be!"

Sewage works men should be comforted to know that detergent manufacturers are aware of the new problems in sewage plants, and are giving technical attention to them. The writer has corresponded with six leading companies, with heartening response in every case. The Federation will continue to cultivate these contacts, so that any information of value, regardless of the source, can be made available without delay. One company, for instance, is studying analytical methods for measuring detergent concentration in solutions, for which there is a great need at the moment.

A number of interesting responses were received from the manufacturers in answer to the question: "Is the sudsing property of a synthetic detergent essential to its effectiveness as a cleansing agent?" The concensus of the replies is as follows:

1. Two of the four companies who replied at length to the query stated that the sudsing type of detergent is somewhat more effective for household purposes. One indicated the sudsing type to be more efficient for dishwashing because of its ability to emulsify fats and oils. The conclusion reached by the writer from all replies is that the suds may be of some value for cleansing but that such advantage is not really significant.

2. The sudsing property is held by the manufacturers to be of value as an indicator to guide the housewife in using the proper amount of detergent. Considerable emphasis was given this advantage.

3. There was no inclination on the part of the manufacturers to minimize the fact that the sudsing property is extremely important to the domestic consumer. Efforts to market household syndets with little or no suds have met with only limited success. The point is

clearly made that the consumer's demand for suds leaves the manufacturer with no choice in the matter, and that a long period of education would be necessary to bring about a change in household washing habits and consumer acceptance of sudsless cleaners.

Manufacturers estimate that the current market ratio of syndets to soap is about one to three.

Information from other sources indicates that the per capita consumption of synthetic detergents has increased from less than 1 to 8 lb. in the period 1942–50, with the total 1950 consumption estimated at 1.2 billion pounds. The 2 billion-pound level is held to be attainable within a relatively short time. To the sewage works man these figures mean that at least twice the present concentration of syndets in sewage can be expected by the time the ultimate market is reached.

The frothing problem has been the only manifestation to cause much concern thus far in sewage works in the United States. There are other potential effects of probably much greater importance. Domestic and industrial water supplies may be appreciably changed in chemical characteristics where sewage effluents are re-used downstream. Physical and biological phenomena in sewage treatment processes may be influenced by eventual concentration levels of detergents. Aquatic life and even some recreational and agricultural uses of receiving waters may be affected. A paper to be published soon in THIS JOURNAL points to the increased concentration of phosphates in stream waters that will be caused by syndets, which is likely to engender problems of algae control.

The FSIWA Board of Control has recognized the far-reaching influence of the changes in sewage characteristics that are resulting from the development of syndets. In 1951 the Board requested several technical committees to give study to the problem, and directed that it be given an important place in the technical program of the 1952 Annual Meeting. The Program Committee has set aside a complete half-day session for a symposium on the subject, and is inviting an impressive list of speakers to participate. A highly significant group of papers is expected here.

In the meantime sewage works personnel should be on the lookout for gradual changes in plant performance, such as lowered sedimentation efficiency, reduced gas production at digesters, interference with secondary treatment and, of course, froth formation. Researchers are urged to study and develop practical analytical methods for the measurement of detergents in sewage. And it is to be hoped that syndet manufacturers will join together to sponsor further plant-scale studies similar to those now being conducted at San Antonio with the help of Proctor and Gamble.

As for the froth fighters, there is nothing like free exchange of experience as a means of overcoming a common problem. THIS JOURNAL welcomes comments on methods that have been tried—successfully or not—to control the froth. So far we understand that water sprays are not a completely satisfactory answer. Mixed liquor solids control will probably abate the nuisance in some cases. The application of defoaming agents, although expensive, may be necessary where conditions are critical. Mineral oils in minute applications to the aeration tank surface have proved effective at Fort Wayne and at the Motherwell sewage works in England (see "The Operator's Corner," this issue).

Finally, let there be no frustration!

W. H. W.

# Reviews and Abstracts*

**Transportation of Coal by Pipeline Studied.** ANON. *Chem. Eng. News*, **29**, 3469 (1951).

A new use for water is the announcement by an Ohio coal company of plans to build 3 mi. of 12-in. pipeline for transporting powdered coal. A more extensive discussion of the cost factors and problems involved is given in a Bureau of Mines report (No. 4799), "Survey on the Hydraulic Transportation of Coal," by R. W. Dougherty. This report can be obtained from Publications Section, Bureau of Mines, 4800 Forbes St., Pittsburgh 13, Pa.

R. S. INGOLS

**l-Carvone from d-Limonene.** BY C. BORDENCA, R. K. ALLISON, AND P. H. DIRSTINE. *Ind. Eng. Chem.*, **43**, 1196 (1951).

As a by-product of the citrus canning industry d-limonene, which makes up about 95 per cent of the orange and grapefruit peel oils, is potentially available in large quantities. The l-carvone is a large constituent of the natural oil of spearmint flavor. The article describes the necessary chemical processes for the conversion of waste of the citrus feed industry into some useful product. R. S. INGOLS

**Protein Evaluations of Yeast Grown on Wood Hydrolysate.** BY E. L. HARRIS, G. J. HAJNY, AND M. C. JOHNSON. *Ind. Eng. Chem.*, **43**, 1593 (1951).

The paper reports on the conditions for the maximum growth of six strains of fast-growing yeast using wood hydrolysate and sulfite waste liquor as a source of sugar. The yeast proteins are deficient in methionine, but with this added, rats develop very well. The yeast uses 90 to 96 per cent of the reducing matter in solution and develops, with proper mineral supplements, 45 to 51 per cent protein. R. S. INGOLS

**Symposium—Resources for the Chemical Industry—Southwest—Raw Material Availability.** BY A. L. BURWELL. *Ind. Eng. Chem.*, **43**, 1727 (1951); and **Water Supplies.** BY P. WEAVER. *Ibid.*, **43**, 1734 (1951).

In both parts of this symposium the limited amount of water available from either ground or surface supplies in certain areas is stressed. The importance of the requirements for irrigation is noted, but the suggestion is made that an industry may be able to use the water and then release it for irrigation, after returning it to a suitable condition. Each article indicates that the water resources may be the limiting factor in a plant location, but wastes treatment may aid in expanding available sites. R. S. INGOLS

**Effect of Copper-Bearing Concrete on Molds.** BY R. F. ROBINSON AND C. R. AUSTIN. *Ind. Eng. Chem.*, **43**, 2077 (1951).

This article describes a copper-bearing concrete which reduces the amount of molds that can develop on its surface, because there is added some copper and arsenic in the substance of the concrete. The concrete is softer with the copper than without it, so that the authors recommend it for covering exposed areas which come in contact with corrosive fumes (such as the walls and ceilings of grit chambers and screen houses). This should be especially helpful in handling stale or septic sewages where hydrogen sulfide oxidation frequently destroys the concrete. R. S. INGOLS

**Crawley New Town—Engineering Works in Progress and Proposed.** BY A. J. W. MCINTOSH. *Surveyor*, **110**, 337 (June 2, 1951).

Crawley is a new town in the vicinity of London, one of eight such to be designated

* Please send to Federation headquarters all periodicals, bulletins, special reports, etc., which might be suitable for abstracting in THIS JOURNAL. Publications of public health departments, stream pollution control agencies, research organizations, and educational institutions are particularly desired. Address such material: Federation of Sewage and Industrial Wastes Assns., 325 Illinois Bldg., Champaign, Ill.

for decentralization of industry and population from Greater London. The designated area is about 3 by 4 mi. in extent, containing about 6,000 acres. The present population is some 10,000, and the ultimate population is to be 50,000 to 60,000.

The area is drained by four main streams, and sanitary trunk sewers will follow approximately the lines of these watercourses. The sewers will drain by gravity to the treatment works at the northeast of the area, except for one area, which will drain to a pumping station, from which a force main will lead to the trunk gravity sewer. Gradients are from 1 in 390 to 1 in 1,000. Sewers will be deep enough to drain 8-ft. basements.

The sewage works are being built in stages with the growth of the town. Treatment is by activated sludge. Land is available for construction of a tertiary stage of treatment by contact filters, if found necessary.

Surface water is to be separately sewered. Each of the catchment areas is being considered in detail, the existing watercourses being widened and deepened or diverted and culverted where necessary. An interesting feature of the design of the surface-water drainage works is the insertion of a flood storage basin at a low point in the area. This basin, of 1,200,000-gal. capacity, may delay for some time the necessity for widening and improvement of streams below this point. Total peak runoff in storms has been calculated to be 49,000 cu. ft. per min.

There are detailed discussions of the plans for water supply and road construction, and mention is made of the proposed systems for gas, electricity, refuse disposal, etc. M. C. RAND

**Sewage Disposal in the Colne Valley—Maple Lodge Works Now in Use.** ANON. *Surveyor*, **110**, 349 (June 9, 1951).

The Maple Lodge sewage disposal works, described in *The Surveyor* of Oct. 17, 1947, are now being brought into use. Sewage was first admitted on May 7, 1951. Only a small flow was admitted, and to avoid septicity, it was diverted directly to one of the activated sludge tanks, bypassing all previous stages. This aeration tank and two of the final clarifiers had been filled with clean water.

Operation in this manner, with settlement and return of the suspended solids, continued for two weeks, during which period the effluents met the required standards at all times. The sewage flow was then increased, and one of the grit channels, a comminutor, and a sedimentation tank, and two more aeration tanks were brought into use.

More sewage will be brought in as the activated sludge builds up and the new sewers are completed. M. C. RAND

**Composting.** BY J. C. WYLIE. *Surveyor*, **110**, 373 (June 16, 1951).

Sewage sludge has agricultural value as a source of slowly available nitrogen, but its physical condition and moisture content restrict its use. Domestic refuse is hardly a manure. Its carbon-nitrogen ratio is so high that its decomposition in the soil causes uptake of nitrogen by the soil organisms rather than its release. When the two substances are mixed to form a compost, the resulting decomposition of carbohydrates and synthesis of organic nitrogen compounds results in a valuable manure.

The composition of sewage sludge from any given source is reasonably constant. But with domestic refuse there are wide seasonal variations, and much of it is inert matter of no agricultural value. It is, therefore, prerequisite that the refuse be sorted, so that larger inert materials may be rejected, and the quantities of compostible materials can be controlled.

If paper, rags, and bones are removed, the remaining compostible materials are (a) fine dust, (b) vegetable content, and (c) combustible debris. The last two fractions should be pulverized before being added to the compost.

Fine dust collections vary widely between summer and winter, and provision must be made for balancing such variations, by storage or disposal of part of the winter collections. Vegetable matter and combustible debris do not store well; the amount used should be fixed at a figure higher than the peak collections and the difference supplied by other carbonaceous matter, such as straw, waste vegetation, sawdust, or seaweed.

Evidence indicates that when temperatures higher than 140°F. are obtained, humus is formed with less loss of organic matter and with a higher nitrogen content than when lower temperatures prevail. Highest temperatures are reached when

the wastes contain a high proportion of carbonaceous matter and there is a balanced condition of moisture and aeration within the compost. It is difficult to apply wet sewage sludge without creating a solid, saturated mass, which is apt to lead to anaerobic conditions.

The wastes must be mixed carefully, and provision must be made for draining off surplus moisture from the bottom. The inclusion of coarse carbonaceous matter, such as straw, aids aeration.

The wastes are mixed by placing in the mixing beds alternate layers of (1) mixed carbonaceous wastes and fine dust, (2) wet sewage sludge, and (3) ground limestone. After sewage sludge is added, excess moisture is drained off and the mixed wastes are forked up before the next layer is added. The final depth of the mass is about 3.5 ft. After three to four days, the mass is transferred to another bed, where it stands six weeks. It is then turned out to mature for six weeks. In all stages, the floor should be raised to allow escape of excess moisture, and there should be protection from rain and the direct force of winds.

Considerable latitude is permissible in the proportion of the various wastes used in the compost, and the proportions may therefore be adjusted to the convenience of each plant.

There is an almost unlimited agricultural market for the sale of mature compost. The cost of transportation may, however, be a hindrance to effective marketing. M. C. RAND

**Future of Sewage Disposal in South Africa,** BY E. J. HAMLIN AND H. WILSON. *Surveyor,* **110,** 397 (June 23, 1951).

There is a shortage of water in South Africa, and greater use must be made of effluents from sewage disposal works. It is quite possible that it will be required that all effluents be sand filtered before discharge into a watercourse. The quality of effluents may have to be better than the standards laid down by the Royal Commission. It appears desirable to construct a storage dam with a detention period of at least seven days, and pass the effluent through the storage dam before discharge.

From an economic point of view, probably greater use will have to be made of sludge gas. On the contemplated works to serve the new gold fields in the Orange Free State, sludge gas will be used for the manufacture of cyanide, which is essential to the gold mining industry.

In most of the larger centers, sewage effluents will be used as circulating water in power stations and industry, as is done at present in Johannesburg and Pretoria.

In better use of industrial wastes, great developments may be expected in South Africa, as elsewhere. The gas recoverable from controlled anaerobic digestion of fermentation and food wastes should suffice to evaporate the residual liquid for recovery of potash, if this is necessary. Alternatively, the gas would provide methane for chemical synthesis, and carbon dioxide for dry ice. In South Africa, sugar cane bagasse is largely used as boiler fuel, but the fiber is suitable for paper making, and in the U. S. is being used to produce good quality newsprint.

The problems to be found in South Africa can only be solved by the cooperation of health officers, engineers, chemists, and managers. Research is essential.

M. C. RAND

**Sewage Works Design.** *Surveyor,* **110,** 419 (June 30, 1951).

This is a report of the discussions of a paper by the same name, by B. F. P. Babcock, which appeared in *The Surveyor* for March 9, 1951.

The view was presented that the best designing practice could only be produced by the man who was thoroughly experienced in operation of a sewage works. For best results, there should be a far greater interchange of personnel between the designing and operating sides. As an alternative, any designing organization should employ at least one experienced operator on its staff.

The opinion was expressed that mechanical removal of sludge from drying beds could never be practical in England unless sufficient drying area were provided to eliminate the need for sludge removal during the winter months.

The need for maximum flexibility of operation was stressed, particularly for large works, which should be so designed that complete sections could be operated as separate units, to permit experimental comparison of various operating methods.

M. C. RAND

**British Water Supply Hampering Chemical Industry.** ANON. *Chem. Eng. News*, **29**, 3162 (1951).

The entire program of technical papers of the July meeting of the Society of Chemical Industries was devoted to the subject of water in industry. The disposal of industrial waste waters was discussed by B. H. Southgate of the British Water Pollution Research Laboratory and by F. W. Mohlman of the Sanitary District of Chicago. R. S. INGOLS

**Food Yeast from Sulfite Liquor.** BY G. C. INSKEEP, A. S. WILEY, J. M. HOLDERBY, AND L. P. HUGHES. *Ind. Chem.*, **43**, 1702 (1951).

A good summary of the operating data of a semi-plant-scale production of food yeast from waste sulfite liquor is presented. The introduction reviews the reasons for the study. A discussion of the basic factors of yeast production is presented with a complete flow sheet of the Rhinelander, Wis., plant of the Lake States Yeast Corp. Analyses of the product show that a good grade of yeast is produced. The equipment and operating problem in the fermentation, aeration tanks, in the yeast separation step, and in the yeast drying phase are described. Cautions concerning the materials of construction in both equipment and housing are given.

The effluent from the food yeast plant shows a B.O.D. removal of approximately 70 per cent. Stripping the free sulfur dioxide from the liquor before using it in the yeast plant reduces the B.O.D. by 10 per cent and improves the ease of handling the yeast while returning a valuable raw material to the paper mill.

Research is in progress on improved aeration and better yeast recovery, but the major factor in the future of food yeast from spent sulfite liquors depends on the degree of cost reduction and yeast production efforts. R. S. INGOLS

**Effect of Fluorine Carriers on Crops and Drainage Waters.** BY W. H. MACINTIRE, S. H. WINTERBERG, L. B. CLEMENTS, L. S. JONES, AND B. ROBINSON. *Ind. Eng. Chem.*, **43**, 1797 (1951).

Because of the increased production and use of materials containing fluorine for insecticides and fertilizers, the authors have studied the effect that the incorporation of various solid carriers exerts upon the fluorine content of vegetation and drainage waters. The results show that very excessive amounts of fluoride were required to induce significant increases in the fluoride content of either crops or drainage water.

Because appreciable concentrations of fluorides are found in industrial wastes these results may be very important.

R. S. INGOLS

**Determination of Trace Amounts of Selenium in Water.** BY J. L. LAMBERT, P. ARTHUR, AND T. E. MOORE. *Anal. Chem.*, **23**, 1101 (1951).

A method for determining trace amounts of selenium in natural or polluted waters is described. All of the seleniferous matter is transformed into selenious acid, which then quantitatively oxidizes iodide to iodine. The iodine is then determined colorimetrically. The method works for concentrations from 0.1 to 5.0 p.p.m. of selenium. Acid bromine solution is used to oxidize the selenium and organic matter. The excess bromine is destroyed with nitrous acid and the excess nitrous acid is destroyed with urea. Many of the original materials in the water which would interfere with the main reactions are taken care of by the excess bromine or the nitrous acid. The color of the trace amounts of iodine is enhanced with starch, which is stabilized by using cadmium iodide instead of the usual potassium iodide.

R. S. INGOLS

**Organic Chemical Compounds in Raw and Filtered Surface Waters.** BY H. BRAUS, F. M. MIDDLETON, AND G. WALTON. *Anal. Chem.*, **23**, 1160 (1951).

The method is designed primarily to aid in the treatment of drinking water supplies by concentrating the trace organic chemicals on a carbon filter and then removing them for identification and study. However, the method is also applicable for the concentration of industrial wastes from a polluted water so that the organic chemical can be traced to its source. Where necessary, a sand filter may proceed the carbon filter. After filtering the water, the carbon filter is treated with ether to remove the organic matter and then the ether solution is fractionated.

R. S. INGOLS

**Some Factors in the Treatment of Sewage in Percolating Filters.** By T. G. Tomlinson and H. Hall. *Proc.*, Pub. Works and Munic. Services Congress (1950).

The results of operation of eight small rectangular filters operated as single units without recirculation for a period of a year are presented and discussed. The B.O.D., suspended solids, oxygen absorption, and the oxidized nitrogen content of the applied sewage and the effluent were determined. Also, the contact time of the liquid passing through the filter was determined and the rates at which oxidizable matter is removed in the filters were calculated. The amount and the composition of the organic film at different depths was also determined. The filters were 4.5 ft. by 8 ft. and 6 ft. deep. One filter contained large gravel (1½-in. to 3-in. size) and the rest crushed gravel of ¾-in. to 1½-in. size. The distributor travels back and forth once in 4 min. The filters were operated continuously at rates of 100 to 1,000 g.p.d. per cu. yd. The sewage treated had an average B.O.D. of 165 ppm.

With increasing rates of application the B.O.D. in the effluent increased, and nearly in a straight-line relationship at rates above 450 gal. per cu. yd. The quantity of B.O.D. removed increased with increasing load, but the proportion of the applied load removed decreased with increasing rates of application. The suspended matter in the effluent varied little with increasing dosages and contained about 85 p.p.m. The B.O.D. of the effluent increased with the B.O.D. of the applied sewage; the greater the rate of application, the greater was the increase in the B.O.D. of the effluent. Better effluents were produced during the summer months than in winter. Appreciable amounts of film occurred at all depths. At the higher rates of dosage the amount of film decreased with depth. The weight of metazoa, fungus, and sludge was determined separately at each depth. It is calculated that the film occupied 60 per cent of the voids in the filter dosed at the rate of 1,000 gal. per cu. yd. Psychoda were present in all the filters at all depths, the largest numbers occurring in the filters dosed at middle rates of 450 to 600 gal. per cu. yd.

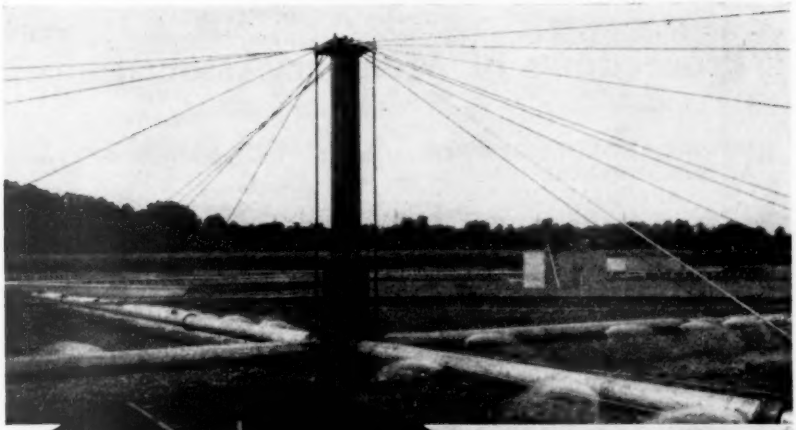
The removal of B.O.D. in per cent, when grouped according to the B.O.D. of the applied sewage, plotted against depth gives a very rapid removal of B.O.D. in the top foot. At greater depths the rate of removal is proportional to the concentration of oxidizable matter present in the liquid. It is assumed that, as in activated sludge oxidation, two monomolecular reactions proceed simultaneously with different velocity constants, one proceeding very rapidly and corresponding to the clarification stage and being completed in the top foot of the filter. This amounts to 19 to 42 per cent of removal of oxidizable material by clarification. The second and slower reaction is represented by a constant which is not affected by the B.O.D. of applied sewage from 123 to 220 p.p.m. The contact times of the filters dosed at different rates were determined by adding ammonium chloride solution to the applied sewage and determining the ammonia in the effluents. The concentration rose to a maximum in 8 min. at 1,000-gal. per cu. yd. rate and in 40 min. at 100-gal. per cu. yd. rate and decreased thereafter logarithmetically, but only 85 per cent of the added ammonia was recovered. The contact time varied from 105 to 110 min. at the 100-gal. per cu. yd. rate to 17 to 20 min. at the 1,000-gal. per cu. yd. rate. By utilizing the contact times thus obtained in the monomelecular formula, a velocity constant for biological filtration of 0.0477 (in minutes) was obtained as compared to a $K$-value of 0.00007 for B.O.D. constant on the same basis (in minutes) and various other values obtained for the activated sludge process. The $K$-values obtained for various rates of application were approximately the same.

H. Heukelekian

**Effluent Filtration Unit Goes into Operation at Humble Oil Refinery.** Anon. *Chem. Eng. News*, **29**, 4276 (1951).

As part of its program of improving quality of refinery effluent discharged to public waters at Baytown, Tex., Humble Oil and Refining Co. put into full-scale operation a new effluent filtration unit. Skimmings are collected in a large sump and filtered with aids on rotary vacuum filters. The sludge is discarded in trenches.

R. S. Ingols



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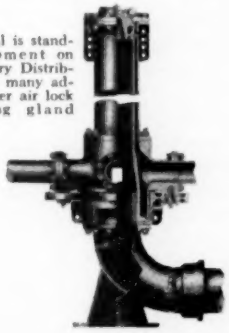

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# Proceedings of Member Associations

## NORTH CAROLINA SEWAGE AND INDUSTRIAL WASTE ASSOCIATION

The 31st Annual Joint Meeting of the North Carolina Sewage and Industrial Waste Association and the North Carolina Section, AWWA, was held at the Robert E. Lee Hotel, Winston-Salem, N. C., November 12–14, 1951. The total registration of members and guests was 242.

The technical program opened with papers as follows:

"Winston-Salem Water Works," by S. E. Harris, superintendent, Water and Sewer Department, Winston-Salem.

"Fluoridation Results from the Dental Viewpoint," by Z. M. Stadt, dental health officer, Charlotte.

The afternoon program was devoted to a waterworks discussion panel led by W. E. Long, water plant superintendent, Fayetteville, N. C. The subjects considered by the panel were: "Reading of Water Meters, Making of Water Bills, Collecting Water Bills"; "Accounting and Public Relations in Connection with These Functions of the Water Department." The panel members were: W. M. Franklin, superintendent, Water Department, Charlotte; Stanford E. Harris, superintendent, Water Department, Winston-Salem; Robert Van Sleen, superintendent of utilities, Shelby; and J. M. Owens, superintendent of water and sewage, Mount Airy.

The panel discussions were followed by an inspection of the recently enlarged Winston-Salem water plant, a buffet supper sponsored by a group of local contractors, and "Pipe Lines to the Clouds," a film prepared by the General Electric Company. The day's activities concluded with an informal dance.

The morning session on November 13 heard the following papers:

"Disposal of Radioactive Wastes in Water and Sewage," by Roy J. Morton, leader, Waste Disposal Research, Oak Ridge National Laboratories, Oak Ridge, Tenn.

"Maintenance of Water Quality," by A. E. Berry, director, Sanitary Engineering Division, Ontario Department of Health, Toronto, Canada.

"The New North Carolina Stream Sanitation Law," by H. G. Baity, professor of sanitary engineering, School of Public Health, University of North Carolina.

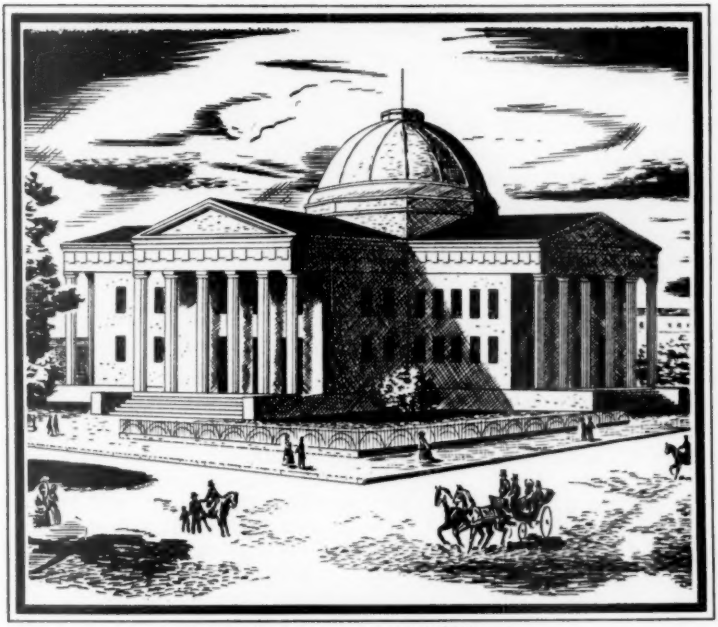
At the Honorary Luncheon for national officers and guests, addresses were given by A. E. Berry, AWWA president, and Earnest Boyce, Federation president. The luncheon was followed by the Annual Business Meeting, at which the following officers were elected for the ensuing year:

*Chairman:* H. F. Davis, Charlotte.
*Vice-Chairman:* J. E. Greenlee, Charlotte.
*FSIWA Director:* P. D. Davis, Durham.
*Secretary-Treasurer:* Earle C. Hubbard, Raleigh.

The remainder of Tuesday afternoon was devoted to a sewage works discussion panel led by W. Brewster Snow, professor of civil engineering, Duke University. The subjects and authors were:

"Financing Sewage Works," by W. E. Easterling, secretary, Local Government Commission, Raleigh.

*(Continued on page 198a)*



*The old courthouse in St. Louis as it looked 100 years ago*

St. Louis, Missouri has a cast iron water main in service that was installed more than 100 years ago. That is not surprising as St. Louis is one of our oldest cities, founded by the French and taken over by the U.S.A. with the Louisiana Purchase. Yet this old main is still withstanding the traffic shock and beam stresses imposed by multi-ton trucks and congested underground utility services in a great manufacturing city. More than thirty other American cities have cast iron water and gas mains in service that were installed over a century ago—indisputable testimony to the strength factors of long life inherent in cast iron pipe.

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"Increasing Costs of Sewage Treatment," by Carl W. Mengel, consulting engineer, Raleigh.

"Purchasing of Supplies," by George S. Moore, superintendent of utilities, Albemarle.

"Disposal of Screenings and Sanitary Land-Fill Operations," by Felix H. Doggett, city engineer, Mount Airy.

At the Annual Banquet and Association Dance, held the evening of November 13, the principal speaker was Tully D. Blair, president, Security Life and Trust Company, Winston-Salem.

The program on the morning of November 14 included the following papers:

"Waste Treatment—An Important Element in Industrial Plant Location," by Truman H. Safford, Chas. T. Main, Inc., Charlotte.

"Biochemical Oxygen Demands of Chlorinated Sewage," by W. Brewster Snow, professor of civil engineering, Duke University.

"Service Charges in Relationship to Sewage Financing," by D. M. Williams, superintendent, Water and Sewer Department, Durham.

The Club Room provided by the Water and Sewage Works Manufacturers Association constituted a very popular phase of the program.

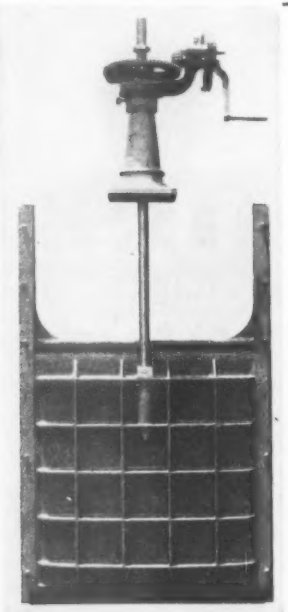
E. C. HUBBARD,
*Secretary-Treasurer*

## NORTH DAKOTA WATER AND SEWAGE WORKS CONFERENCE

The 23rd Annual Convention of the North Dakota Water and Sewage Works Conference was held at the Gardner Hotel, Fargo, N. Dak., September 26–28, 1951. Registration for the meeting totaled 134.

The pre-convention Smoker and Dutch Lunch on September 26 was

(*Continued on page 200a*)



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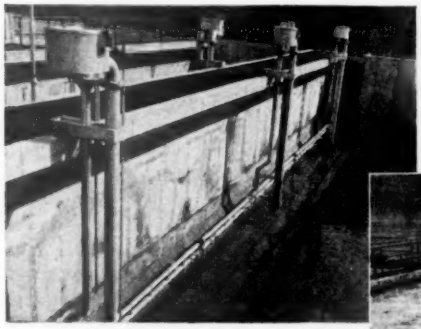
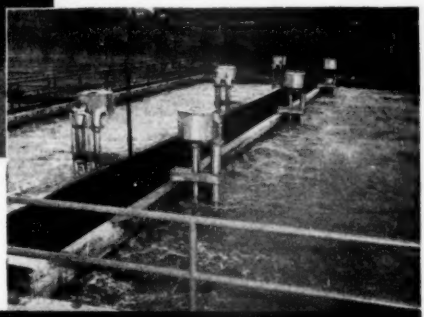


DIFFUSAIR installation at Kirkwood, Mo. Impingement nozzles and bowls are on headers at lower left side of tank.



DIFFUSAIR at Kirkwood, Mo. in operation showing effective "spiral flow" agitation and aeration of tank liquor.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The impingement liquor is derived directly from the aeration tank mixed liquor, and is lifted with a simple air-lift unit from which 1/3 of the fine air is re-entrained and utilized for oxygenation.

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well-attended and gave an opportunity for getting acquainted and exchanging operating information.

Papers of interest to sewage works personnel included:

"Paints and Protective Coatings for Water and Sewage Equipment," by George Kronschnabel, Inertol Co., St. Paul, Minn.

"Fluoridation," a panel discussion by representatives of equipment and chemical supply companies and the State Health Department.

"Sludge Digestion," by W. N. Lauer, Dorr Co., St. Paul, Minn.

"Interpretation of Section 111.0 of State Plumbing Code," by Jerome H. Svore, State Health Dept., Bismarck.

"Progress of Pollution Control in the United States," by Paul W. Reed, U.S.P.H.S., Chicago, Ill.

"Materials Procurement," by Robert N. Huey, NPA Office, Fargo.

"Engineering Needs and Values," by E. L. Lium, Dean, School of Engineering, Univ. of N. Dak.

"What Happens in an Imhoff Tank," by Arthur E. Williamson, State Health Dept., Bismarck.

A group discussion for sewage works operators covered a wide range of subjects, including sewer cleaning methods, ways of eliminating or controlling rats in sewers, lift station controls, treatment plant operation, public relations, and the effects of garbage grinders on sewage treatment. The meeting closed with an inspection tour of the Fargo water and sewage treatment plants.

Officers elected to serve during 1951–52 were:

*President:* K. Johnson, Dickinson.
*Vice-President:* E. Booth, Bismarck.
*Secretary-Treasurer:* J. H. Svore, Bismarck.

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# Equipment and Supply Lines

**Strip Chart Recorder**—Specification Sheet 769 illustrates miniature strip chart recorders and gives application data.—Minneapolis-Honeywell Regulator Co., Brown Instruments Division, Wayne and Windrim Aves., Philadelphia 44, Pa.

**pH Recorders and Controllers**—A new 40-page catalog (15–16) includes fundamentals of pH measuring systems, details of components, and typical applications of pH measuring and recording equipment.—Minneapolis-Honeywell Regulator Co., Brown Instruments Division, Wayne and Windrim Aves., Philadelphia 44, Pa.

**Capacitor Motors**—Freedom from vibration and extra-quiet operation are claimed for a new line of single-phase, capacitor, induction motors in sizes from ½ to 5 h.p.—General Electric Co., Schenectady 5, N. Y.

**Packaged Power**—New 24-page Bulletin GEA–5600 describes use of "packaged" electrical systems built up of standardized components to reduce critical material usage and save time and money in construction and expansion programs.—General Electric Co., Schenectady 5, N. Y.

**Flow Ratio Controllers**—Catalog 53, describing the unusual features of this firm's Automatic Flow Ratio Control Systems, has been recently made available.—Fischer & Porter Co., Hatboro, Pa.

**HTH Tablets**—A unique product-equipment combination, by which high-test calcium hypochlorite tablets are dissolved in a new Hypochlorinator, has been announced. The new chlorination method has been designed for applications where a slow steady release of available chlorine is desired.—Mathieson Chemical Corp., Mathieson Bldg., Baltimore 3, Md.

**Flotation Separator**—Bulletin No. F1 describes the principle, operation, and construction of the Sveen Pedersen Flotation Saveall for suspended solids removal and water recovery.—Sveen Pedersen Sales Corp., 35–41 Eleventh St., Long Island City 6, N. Y.

**Process Industry Equipment**—Newly published 12-page Bulletin 50–I describes process industry equipment and its application to water, sewage, and industrial wastes treatment.—Infilco, Inc., Box 5033, Tucson, Ariz.

**Comminutor**—Revised Bulletin 5100–A gives data and details on Griductor for sewage screening and cutting.—Infilco, Inc., Box 5033, Tucson, Ariz.

**Pipe Coupling**—Data on low-pressure Wedge-Lock coupling for lightweight steel pipe in ventilating and temporary lines are given in Bulletin 514.—Naylor Pipe Co., 1230 East 92nd St., Chicago 19, Ill.

**Ash Handling Systems**—A new booklet gives detailed information on ash and flyash handling systems.—Beaumont Birch Co., 1505 Race St., Philadelphia 2, Pa.

**Ring Packing**—A new automatic ring packing designed for maximum sealing efficiency in minimum packing depth is available in varied compositions to suit different services.—Johns-Manville, 22 East 40th St., New York 16, N. Y.

**Feeders and Conveyors**—Catalog 830 describes electric vibrating feeders and conveyors and gives specifications and installation details. Also included are descriptions of weighing feeders, coolers and dryers, bin valves and level indicators, magnetic separators, ers and pulverizers, and other materials-handling equipment.—Jeffrey Manufacturing Co., Columbus 16, Ohio.

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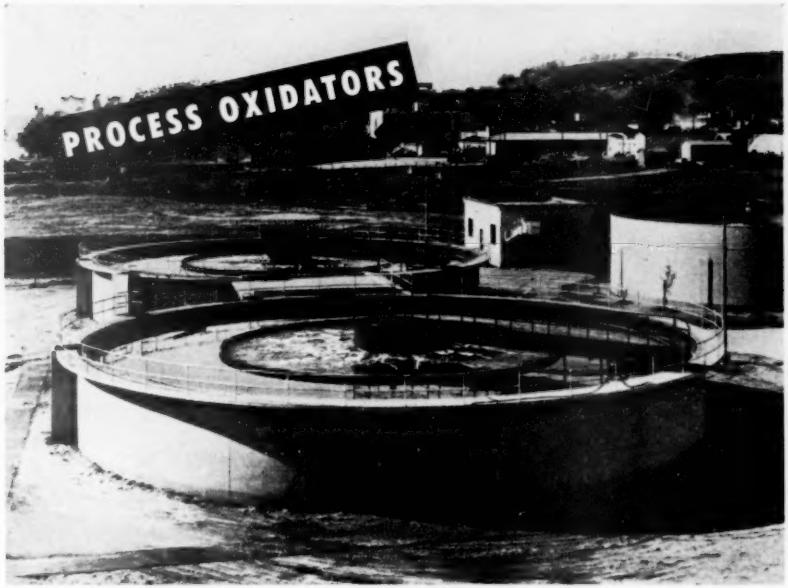


# *The Picture that Speaks for Itself!*

THIS is a graphic illustration of the Process Oxidator* at work. Shown are two single stage, 80 ft. dia. Oxidators at the new Santa Barbara, California Sewage Treatment Plant designed for a population of 60,000 by Koebig & Koebig, Consulting Engineers.

The Oxidators combine aeration, coagulation and sedimentation in a single circular tank giving the results of intermediate treatment at practically the cost of primary treatment. Note the excellent aeration in the center well and the absence of scum in the sedimentation compartment.

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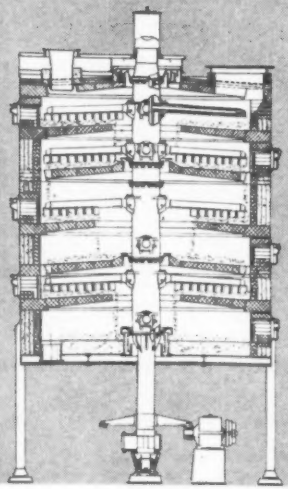

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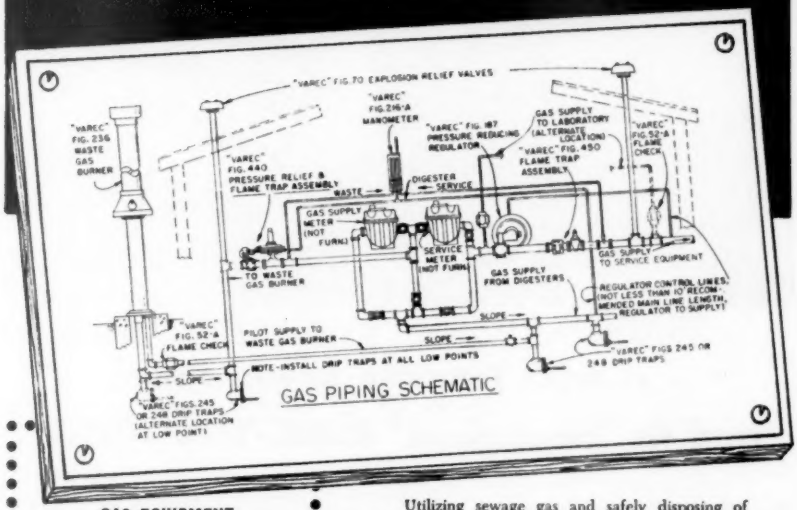
"VAREC" FIG. 70 EXPLOSION RELIEF VALVES
"VAREC" FIG. 236 WASTE GAS BURNER
"VAREC" FIG. 216-A MANOMETER
"VAREC" FIG. 187 PRESSURE REDUCING REGULATOR
GAS SUPPLY TO LABORATORY (ALTERNATE LOCATION)
"VAREC" FIG. 52-A FLAME CHECK
"VAREC" FIG. 440 PRESSURE RELIEF & FLAME TRAP ASSEMBLY
"VAREC" FLAME TRAP ASSEMBLY FIG. 450
WASTE
DIGESTER SERVICE
GAS SUPPLY METER (NOT FURN.)
SERVICE METER (NOT FURN.)
GAS SUPPLY TO SERVICE EQUIPMENT
TO WASTE GAS BURNER
GAS SUPPLY FROM DIGESTERS
REGULATOR CONTROL LINES: (NOT LESS THAN 10' RECOMMENDED MAIN LINE LENGTH, REGULATOR TO SUPPLY)
"VAREC" FIG. 52-A FLAME CHECK
PILOT SUPPLY TO WASTE GAS BURNER
SLOPE
SLOPE
SLOPE
NOTE—INSTALL DRIP TRAPS AT ALL LOW POINTS
"VAREC" FIGS 245 OR 248 DRIP TRAPS
"VAREC" FIGS. 245 OR 248 DRIP TRAPS (ALTERNATE LOCATION AT LOW POINT)
GAS PIPING SCHEMATIC

## GAS EQUIPMENT SPECIFICATIONS

a. **PRESSURE RELIEF AND FLAME TRAP ASSEMBLY**
"VAREC" Fig. No. 440

b. **FLAME TRAP ASSEMBLY**
"VAREC" Fig. No. 450

c. **FLAME CHECK**
"VAREC" Fig. No. 52A

d. **EXPLOSION RELIEF VALVES**
"VAREC" Fig. No. 70-1

e. **WASTE GAS BURNER**
"VAREC" Fig. No. 236

f. **DRIP TRAPS**
"VAREC" Fig. No. 245 (automatic)
"VAREC" Fig. No. 248 (hand operated)

g. **MANOMETERS**
"VAREC" Fig. No. 216A

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An enlarged engineering drawing of the above gas piping detail will be sent upon request. If you design sewage treatment plants, write today.

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The photograph above shows the total amount of infiltration—through manholes as well as pipe—in a recently installed sewer system consisting of 5 miles of 6″, 8″, 12″ and 18″ diameter Transite Sewer Pipe. So little ground water entered the system that the only practical way it could be measured was by inserting a 3″ pipe in the Parshall flume as shown here!

Here is visual proof that Transite Sewer Pipe with its Ring-Tite Joint cuts ground water infiltration to a minimum—in this case less than 3.4% of the specified allowable of 600 gallons per inch of pipe diameter, per mile, per day.

The Ring-Tite Joint, standard on all sizes of Transite Sewer Pipe, has other important practical advantages, too. Actually a factory-made joint, it can be assembled in a fraction of the time required for making ordinary sewer pipe joints. No jointing compounds are used—just a simple assembly operation with a mechanical coupling puller does the job. And you can check each joint for proper assembly as soon as it is made—*and backfill immediately!*

Transite Sewer Pipe may also help you save in other ways. Its long 13-foot lengths mean *fewer* joints to make—thus further reducing installation expense. And its high flow capacity (Manning's n=.010.) often permits flatter grades and shallower trenches—a particularly important economy where pipe is laid at or below the ground water line or where rock excavation is required.

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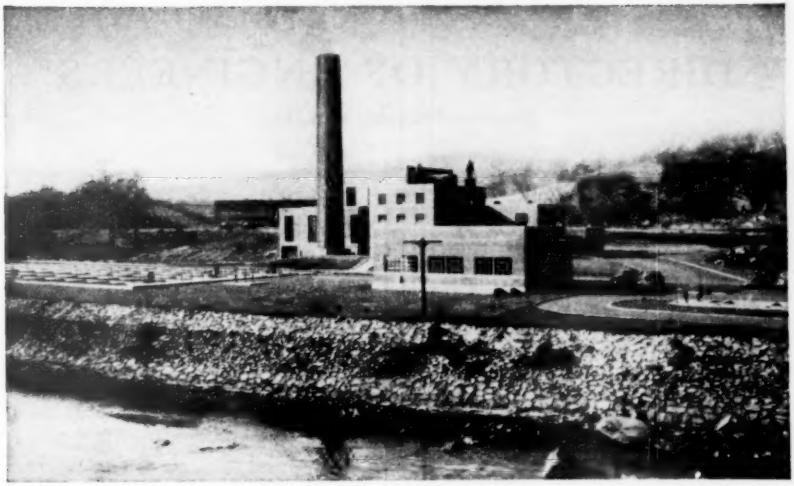

# New Waterbury Disposal Plant ...flash dries sewage sludge

A large forward step in lowering pollution in Connecticut's Naugatuck River was taken when the city of Waterbury opened its new disposal plant recently. Combining refuse incineration with sludge disposal and high temperature deodorization, the Waterbury plant effectively disposes of wastes for an equivalent population of 100,000.

The C-E Raymond Flash Drying Unit in this new plant is designed to dry over 29 tons of filter cake per day. This is equivalent to an evaporation rate of 2600 pounds per hour. The plant is designed so that the sludge can be dried and marketed as fertilizer, or incinerated to a sterile ash.

The Waterbury plant is typical of C-E Raymond System installations, now in service in virtually all parts of the country, meeting the varying requirements of both large and small communities. They are flexible in layout, highly efficient and thoroughly reliable; they provide for maximum utilization of waste heat.

The services of C-E specialists are available to assist you in finding the best solution to *your* sludge disposal problem. Get in touch with the C-E office nearest you for prompt attention. B-561A

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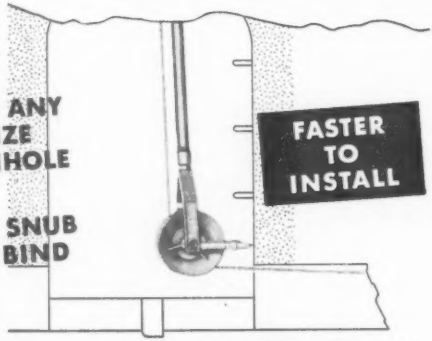


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## INDEX TO ADVERTISERS


| | Page |
|---|---|
| American Cast Iron Pipe Company | 180a |
| Armco Drainage & Metal Products, Inc. | 204a |
| Builders-Providence, Inc. | 175a |
| Cast Iron Pipe Research Association | 192a |
| Chain Belt Company | 136a |
| Chapman Valve Manufacturing Company | 203a |
| Chicago Pump Company | 173a |
| Combustion Engineering—Superheater, Inc. (Flash Dryer Div.) | 209a |
| Dorr Company | 194a |
| Economy Pumps, Inc. (C. H. Wheeler Mfg. Co. Div.) | 188a |
| Flexible Sewer-Rod Equipment Company | 216a |
| General American Transportation Company (Wiggins Gasholder Div.) | 181a |
| General Electric Company | 191a |
| Inertol Company, Inc. | 183a |
| Infilco, Inc. | 134a |
| Jeffrey Manufacturing Company | 189a |
| Johns-Manville Corporation | 208a |
| Lock Joint Pipe Company | 182a |
| Magnetite Filter Corporation | 200a |
| National Clay Pipe Manufacturers, Inc. | 187a |
| Nichols Engineering & Research Corporation | 206a |
| Pacific Flush Tank Company | 195a |
| Process Engineers, Incorporated | 205a |
| Rockwell Manufacturing Company (Nordstrom Valve Division) | 185a |
| Simplex Valve and Meter Company | 177a |
| Snow Irrigation Supply Company | 198a |
| Thermoc Company, Inc. | 204a |
| U. S. Pipe & Foundry Company | 197a |
| Vapor Recovery Systems Company | 207a |
| Walker Process Equipment Company | 199a |
| Wallace & Tiernan Company, Inc. | Back cover |
| Worthington Pump and Machinery Corporation (Public Works Div.) | 130a |
| Yeomans Brothers Company | 179a |


## DIRECTORY OF ENGINEERS, pp. 210a–215a


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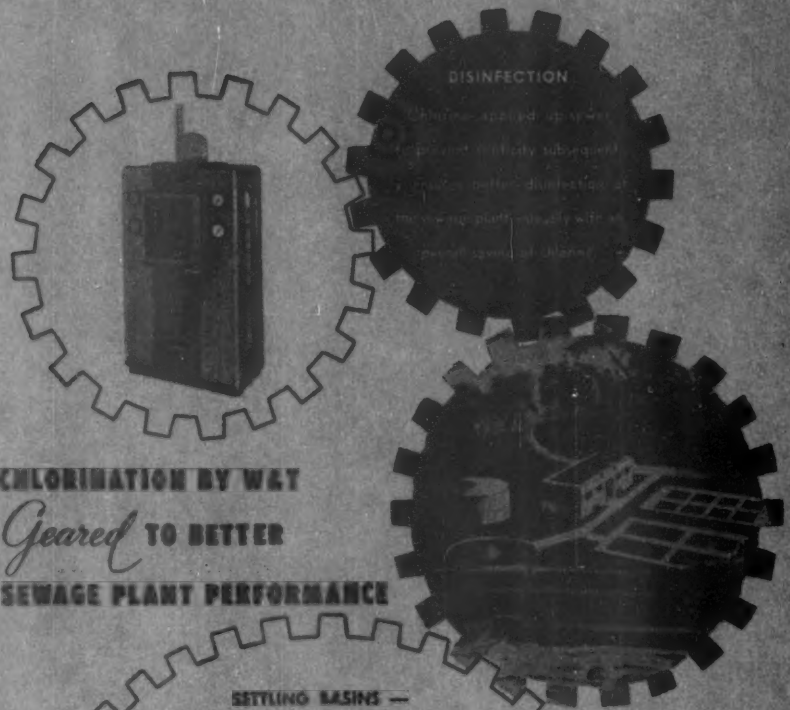


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